Water Resources Report Number 45

MISSOURI STATE WATER PLAN SERIES

VOLUME 1

Surface Water Resources of Missouri

MISSOURI DEPARTMENT OF NATURAL RESOURCES

Division of Geology and Land Survey

COVER:

Groundwater merges with surface water in Blue Spring branch near the Current River in Shannon County. Blue Spring, 6th largest in Missouri, adds an average of 90 million gallons of water each day to the Current River. Photo by Jim Vandike.

Missouri State Water Plan Series Volume 1

Surface Water Resources of Missouri

by
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PREFACE

MISSOURI STATE WATER PLAN TECHNICAL VOLUME SERIES

The Missouri Department of Natural Resources State Water Plan Technical Volume Series is part of a comprehensive state water resource plan. This portion is designed to provide basic scientific and background information on the water resources of the state. The information in these technical volumes will provide a firm foundation for addressing present and future water resource needs and issues. Each volume in the series deals with a specific water resource component.

Volume I

The ***Surface Water Resources of Missouri*** contains a basin-by-basin assessment of Missouri's surface water resources. It discusses the effects of climate, geology and other factors on the hydrologic characteristics of major lakes, streams and rivers. It also assesses surface-water availability and development in the state.

Volume II

The ***Groundwater Resources of Missouri*** presents information on the availability and natural quality of groundwater throughout the state. It focuses on Missouri's seven groundwater provinces and includes their geology, hydrogeology, areal extent, general water quality, and potential for contamination. Aquifer storage estimates are given for each aquifer and county. The report also reviews the different types of water-supply wells in use and how water well construction techniques vary between areas and aquifers.

Volume III

Missouri Water Quality Assessment focuses on the current quality of Missouri surface water and ground-water. The volume looks at chemical, bacteriological and radiological water-quality, and natural and man-induced water-quality changes.

Volume IV

The ***Water Use of Missouri*** describes how Missouri is presently using its surface-water and groundwater resources. The report covers private and public water supplies, industrial and agricultural water uses, and water use for electrical power production, navigation, recreation, fish and wildlife.

Volume V

Hydrologic Extremes in Missouri: Flooding and Drought provides basic information about flooding and drought specific to Missouri. A historical perspective is given, as well as information that can be used in planning for hydrologic extremes. It also describes concepts and defines terminology helpful in understanding flood and drought.

Volume VI

Water Resource Sharing - The Realities of Interstate Rivers presents Missouri's views concerning interstate rivers. Because of its location, Missouri can be greatly affected by activities and water policy in the upper basin states of the Missouri and Mississippi river basins. Missouri policy can also affect downstream states on the Mississippi, Arkansas and White rivers. Many serious issues affecting these rivers have less to do with their physical characteristics than with political, economic and social trends.

Volume VII

Missouri Water Law provides an overview of the laws that affect the protection and use of Missouri's water resources. It supplies reference information about existing doctrines, statues and case law.

EXECUTIVE SUMMARY

Missouri depends greatly on its surface-water resources for drinking, agricultural, commercial and industrial water supply, river transportation, fish and wildlife habitat, electrical generation, recreation, and many other uses. Current estimates indicate that surface water supplies nearly 90 percent of the total off-stream water use, which is about 2.3 trillion gallons per year.

During a normal precipitation year, approximately 12 trillion gallons of water are supplied to Missouri by runoff from precipitation within the state. Rainfall statewide averages about 38 inches, with about 10 inches becoming surface-water runoff or groundwater recharge. The remaining 28 inches are returned to the atmosphere by evaporation or plant use.

Runoff from upstream states increases the amount of surface water that is available. Water entering Missouri from the upper Mississippi and Missouri rivers combined averages about 37 trillion gallons per year. Most of this surface water passes through the state in a few days. Thus, during extended droughts, considerably less surface water is available to meet Missouri's needs.

The Missouri River drains more than 52 percent of the state, an area of about 36,537 square miles. The state provides only about 6.9 percent of the total drainage area of the Missouri River basin, but contributes a much higher percentage of the river's flow. Based on nearly 100 years of flow records, about 35 percent of the flow of the Missouri River at Hermann is from runoff in Missouri. The remaining 65 percent is runoff from upstream states.

The volume of surface water in Missouri is generally adequate to meet most needs, but the resource is not evenly distributed across the state. Northern and west-central Missouri have relatively poor groundwater resources, and rely on surface water for most of their water-supply needs. These areas also have lower average rainfall rates than the rest of the state, and groundwater does not contribute appreciable volumes of water to streams and rivers. Thus, many towns in northern and west-central Missouri, especially those some distance from a major river, use reservoirs for their water supply. Of the approximately 123 reservoirs currently in use as public water supply sources, all but eight are in west central and northern Missouri where groundwater resources are poor.

Surface-water intakes on major streams and rivers are used by approximately 50 cities where streams have adequate low flows. Twenty of the 50 use reservoirs to impound surface-water runoff, as well as river intakes to help keep reservoirs filled during periods of low runoff.

The Missouri and Mississippi rivers supply municipal water to about one-third of the state's population. Nearly 60 percent of the population of Missouri is in the 25 counties that border the Missouri River. As water needs increase, both the Missouri and Mississippi rivers will become even more important water resources.

Surface water is used much less in the southern part of the state as a water supply. A few towns rely on surface water for part or all of their municipal water-supply needs in this region, but groundwater is typically used for private as well as public water supply. In southern Missouri, the emphasis on surface water shifts from drinking water to recreation. Large lakes in the Osage and White river basins attract millions of visitors each year, and tourism in these areas is a very important industry for the state. The lakes also provide flood protection for downstream areas, and many provide hydroelectric power.

In the Ozarks region, much of the runoff from upland areas percolates downward through permeable surficial materials, or is channelled underground by losing streams, and sinkholes. The high rate of groundwater recharge in the Ozarks greatly affects the rivers and streams. Much of the groundwater in the Ozarks flows through cave-like systems to springs along major streams and rivers. The large springs tend to have fairly uniform flow characteristics, and provide well-sustained flows to streams even during dry weather. The swift, clear, spring-fed streams and rivers that characterize the Ozarks are popular recreational areas, and contribute greatly to the economic well-being of the state.

The overall quality of surface water in Missouri is relatively good. Most of the elements dissolved in the water are within recommended drinking-water parameters in almost all areas. Bacteria is contained in all surface water; the level of bacteria is generally directly proportional to the amount of development in the watershed. Both wastewater discharges and agricultural runoff increase bacteria levels in surface water. Suspended solids vary greatly with stream stage and location, but are generally the highest in northern and western Missouri where row-cropping is common and soils are more easily eroded. The lowest amount of suspended solids in surface water in the Ozarks is where timber and grassland are most prevalent. Throughout the state, suspended solids are highest during floods, and lowest during normal or low-flow conditions.

INTRODUCTION

In Missouri, the availability of abundant, good-quality water is one of the state's most important natural resources. Missouri water resources consist of both surface water and groundwater. Surface water is that part of the total resource that rests upon the Earth's surface. It is the water found in rivers, streams, lakes, and reservoirs. Groundwater is that part of the total resource that is found beneath the Earth's surface in formations called aquifers. Combined, they form the total water resource of the state.

Missouri is often thought of as a state of rivers and streams. Most of its eastern boundary is formed by a 485-mile stretch of the Mississippi River. The Mississippi River has its headwaters in Lake Itasca, Minnesota, and flows 2,440 miles to the Gulf of Mexico. It drains about 923,500 square miles, or 30 percent of the continental United States (MGS, 1967). The Des Moines River forms 20 miles of Missouri boundary in the northeast corner of the state. The Missouri River forms the border from Iowa to the Kansas River at Kansas City, a distance of 185 miles. About 375 miles farther downstream on the lower Missouri River, near St. Louis, the Missouri and Mississippi rivers merge to form one of the largest river systems in the world. A much smaller river, the St. Francis, forms the western boundary of the state in the Bootheel. The Ohio River enters the Mississippi in the northern part of the Bootheel. Although the Ohio does not cross into Missouri, its waters certainly affect the state.

Being at the juncture of the Missouri, Mississippi and Ohio rivers, the state of Missouri is affected by water draining from the north-central United States between the Rocky Mountains and the Appalachians as well as a small part of southern Canada.

Overall, Missouri has excellent surface water and groundwater resources. Both are ultimately supplied and replenished by precipitation. Precipitation varies widely, but in an average year, about 38 inches of precipitation falls on Missouri's 69,709 square mile area. This provides a volume of nearly 46 trillion gallons, enough to supply more than 24,000 gallons a day to each of the state's 5,117,073 residents. In addition, millions of gallons of water enter Missouri each day from adjoining upstream states, further increasing the resource base. Another 3.29 trillion gallons of water is contained in the 12 major Corps of Engineers reservoirs that are entirely or partially within the state; a volume of water that would supply every resident of Missouri 100 gallons per day for more than 17 years. Missouri groundwater reserves are estimated at more than 43 trillion gallons (Miller and Vandike, 1996).

At first glance, when the total resource is considered, it may seem difficult to imagine how Missouri could ever suffer from water shortages. Compared to the arid western states, Missouri is generally considered to be rich in water. However the above figures, though reasonably accurate, do not fully portray all aspects of Missouri's water resources.

First, only a fraction of the total rainfall received by the state is available for either surface-water runoff into lakes or streams, or for providing recharge to groundwater. Much of the water is returned to the atmosphere by evaporation or is transpired by plants. The 38-inch average rainfall value for Missouri is only that--an average. Yearly rainfall at any given place in the state may range from less than one-half of this value to more than twice the average amount.

Second, the seasons of highest rainfall do not typically coincide with times of greatest need. Much of the precipitation during a given year is in the spring. Periods of greatest need are typically in late summer.

Third, the total volume of water used in the state is far greater than the amount used for individual and municipal water supply. Generally, an individual uses from 50 to 150 gallons of water per day for domestic needs. Water for agricultural irrigation, hydroelectric generation, thermoelectric cooling, and other industrial, commercial, and agricultural needs accounts for most of the water used, which is an estimated 1,354 gallons per day per person (Reed and others, 1993). Much of this is nonconsumptive (the water being returned to the stream or lake for further use) but the total volume of water needed to meet these demands is still required. Not considered in the above discussion is water for fish and wildlife, aquatic recreation, water-quality mitigation, and river transportation. Economics should also be considered. For numerous reasons, surface water is not suitable for many uses without expensive treatment. A town of 500 people in northern Missouri where groundwater may be highly mineralized, might find it very difficult and costly to purchase land for a reservoir, build the reservoir, construct the treatment plant, and treat and distribute the water. A town of the same size in an area where potable groundwater resources can supply the needed volume could develop a public water supply much more economically.

Water resources are also not evenly distributed throughout the state. Northern Missouri generally has the lowest average rainfall. It also has the poorest groundwater resources--water which cannot be depended upon to alleviate shortages during drought. And the Bootheel area of southeastern Missouri has abundant groundwater resources and the highest rainfall in the state, but here, the problem is generally too much water rather than too little.

Normally water problems do not occur during the average conditions discussed above; instead they occur during extreme climatic circumstances that produce either flooding or drought. Droughts are a silent blight because they slowly strangle crops and grassland and deplete water-supply reservoirs. During this century alone, droughts in Missouri have caused billions of dollars in damage. Much of the damage has been due to the loss of agricultural products or river transportation. Because they affect larger areas, the overall economic losses due to drought are generally greater than those from floods. However, a major flood can scar a river for years and devastate the communities along it. In 1993, heavy rainfall throughout the upper Mississippi River basin, as well as parts of the Missouri River basin, caused record flooding on the Mississippi River and many of its tributaries in the state. On August 1, 1993, the Mississippi River at St. Louis peaked with a discharge of 1,080,000 cubic feet of water per second (ft^3/sec). If Lake of the Ozarks was empty, this flow rate would fill it in less than 22 hours.

The purpose of this report is to provide a description of the surface water resources of Missouri. As part of the framework of the **Missouri State Water Plan**, this report will discuss the hydrologic cycle as it relates to surface water, evaluate overall surface-water resources and provide detailed descriptions of selected surface watersheds throughout Missouri. Drought, flooding, water use, and water quality will be discussed in general, but each of these important topics will be more fully examined in future volumes of the **Missouri State Water Plan**.

In this report, the discharges of rivers and springs are reported in units of cubic feet of water per second (ft^3/sec). One cubic foot per second is equal to 448.9 gallons per minute, or 646,358 gallons per day. The storage of lakes and yearly volumes of runoff are generally reported in units of acre-feet (ac-ft). One acre-foot of water is the volume of water necessary to cover an area of one acre (43,560 ft^2) to a depth of one foot. One acre-foot of water is equal to 43,560 ft^3, or 325,872 gallons. Runoff rates for river basins are generally reported in units of inches per year (in./yr). A stream having a runoff rate of one inch per year would, in one year, discharge enough water to cover the entire watershed to a depth of one inch.

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PHYSIOGRAPHY AND CLIMATE

The surface water resources of Missouri are, to a great extent, controlled by physiographic and climatological factors. Being in the mid-continent region, the topography of the state is considerably more gentle than that of the mountainous areas to the east and west. However, Missouri's physical features are more varied than many of those of the bordering states.

Missouri contains three distinct physiographic regions that can be further subdivided, based on more subtle changes. Missouri's landscape is characterized by plains north of the Missouri River, and in the west-central part of the state. Southeastern Missouri, at the northern end of the Mississippi Embayment or coastal plain, is a lowland. Between these two regions lie the Missouri Ozarks, an uplifted area of considerably more rugged character than the state's other provinces. The total topographic relief for Missouri is about 1,540 feet. Figure 1 shows the physiographic provinces in Missouri, and figure 2 is a generalized geologic map of the state. Table 1 shows the general stratigraphic sequence (layered arrangement) of rock units in Missouri, and their hydrologic (water-related) significance.

NORTHERN MISSOURI

Unlike most of the state, the physical characteristics of northern Missouri were altered by glaciers during the Pleistocene Epoch or Ice Age. Advances and retreats of two major ice sheets left behind thick deposits of unconsolidated glacially derived sediments covering a pre-existing topography developed on Pennsylvanian- and Mississippian-age bedrock.

The glacial till, consisting of clay, silt, sand, gravel and boulders, has been dissected by runoff. This erosion is gradually destroying the level plains-like topography formed by glaciation. The resulting drainage pattern consists of nearly parallel streams that, in northwestern Missouri, trend to the south and drain into the Missouri River. Streams in northeastern Missouri, which drain directly into the Mississippi River, have a distinct southeasterly trend.

Elevations in northern Missouri range from about 1,200 feet above mean sea level (msl) along major drainage divides in northwestern Missouri to about 600 feet msl along the Missouri and Mississippi rivers. The southern extent of glaciation roughly parallels the Missouri river. It ends a few miles south of the river on the western side of the state, and a few miles north of the river in most of the eastern side.

OSAGE PLAINS

The Osage Plains of western Missouri is an area of relatively low relief with an even more gentle topography than northern Missouri. Here plains are not due to glaciation. Rather, this area is underlain by Pennsylvanian-age sedimentary rocks consisting of relatively thin limestones, sandstones, and shales. Soils in the area are thin, runoff is rapid, and there is very little groundwater recharge. Elevations range from about 1,000 feet msl along drainage divides near the Kansas border to about 680 feet msl in the eastern part of the area along the Osage River. Most of the Osage Plains drains to the east and north into the Missouri River; however, the southern tip of the province drains south and west into Oklahoma to the Arkansas River.

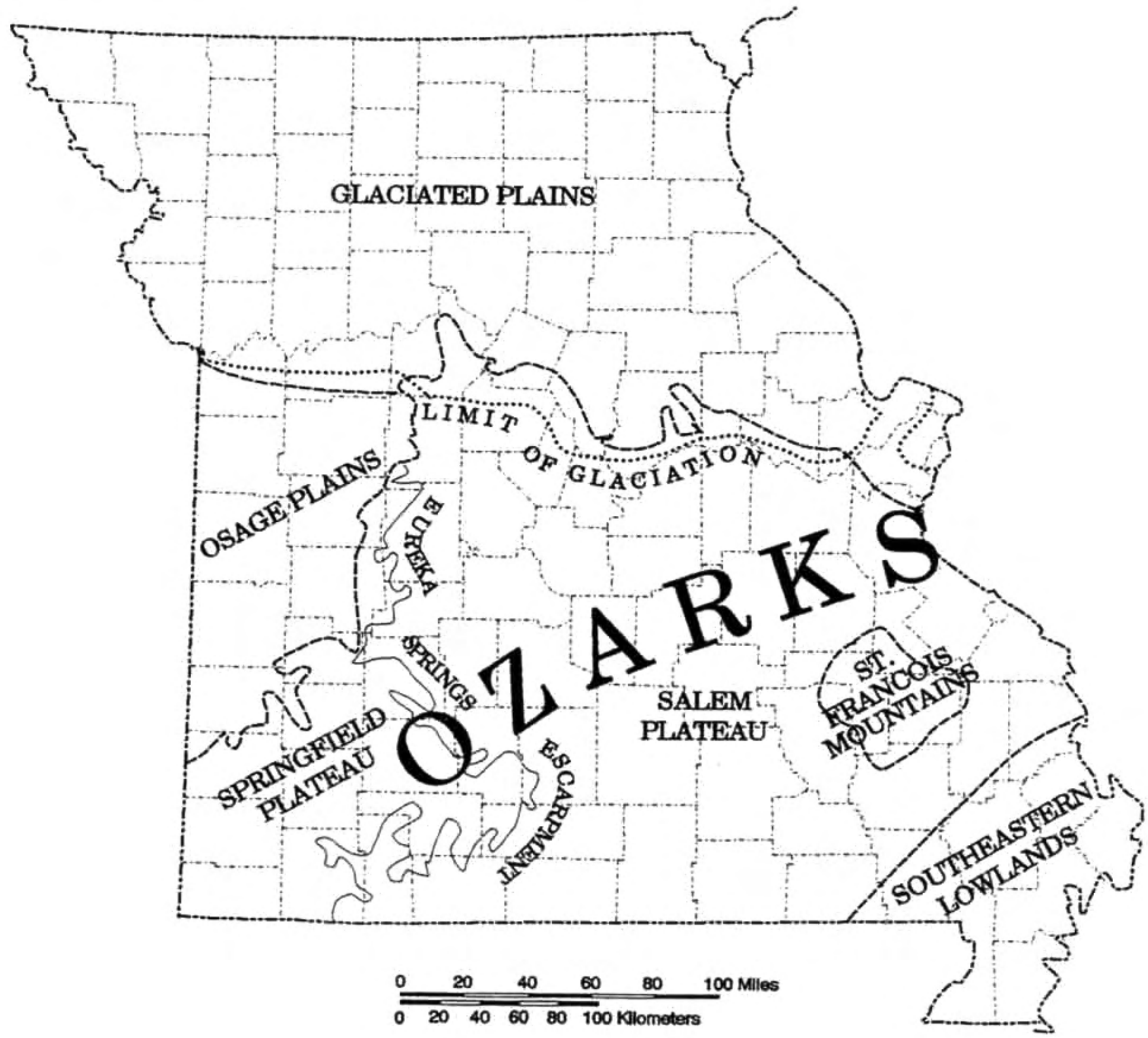

Figure 1. Physiographic regions of Missouri.

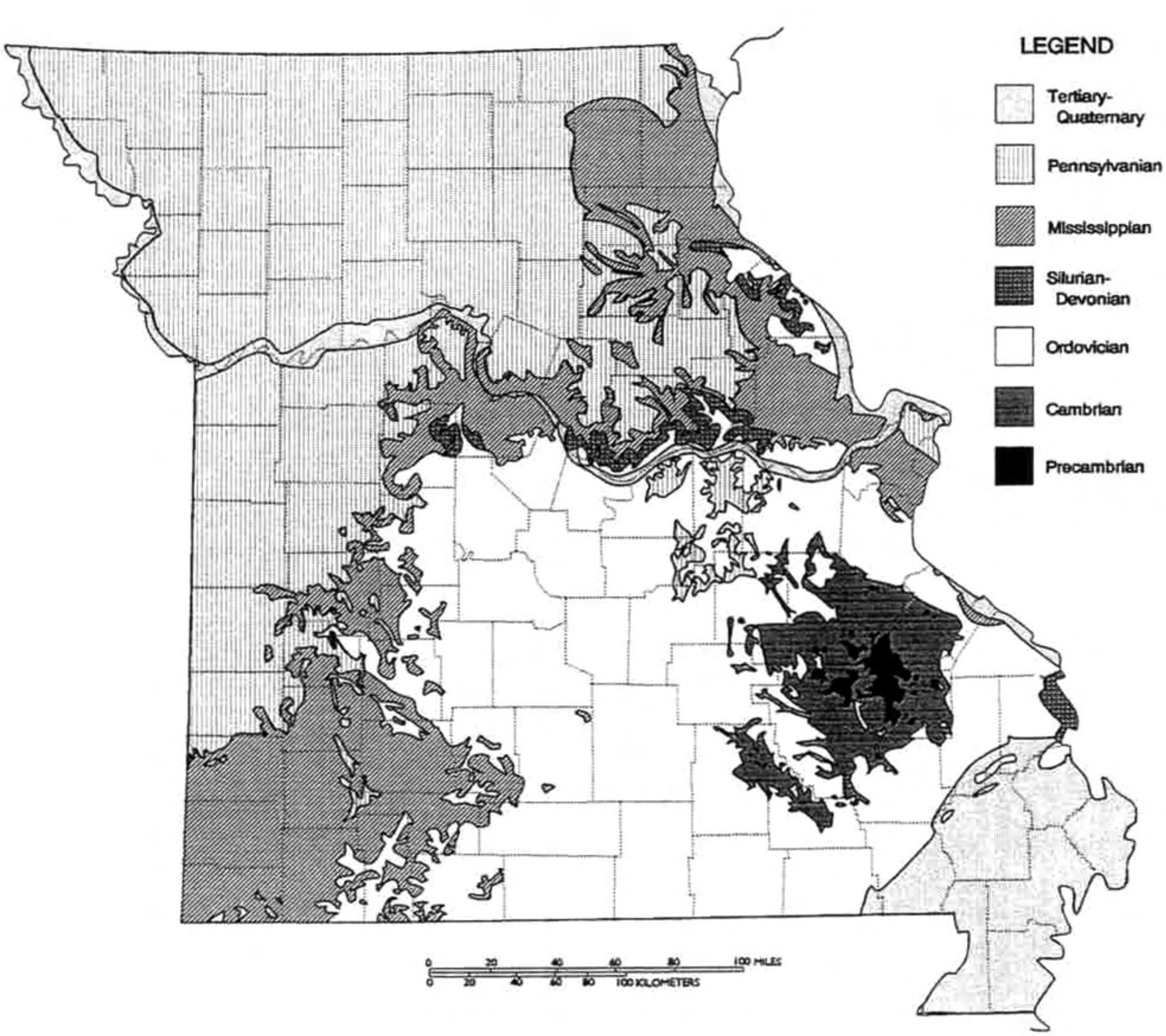

Figure 2. Generalized geologic map of Missouri.

<table>
<tr><th>SYSTEM</th><th>SERIES</th><th>GROUP</th><th>GEOLOGIC UNIT</th><th>HYDROGEOLOGIC UNIT</th></tr>
<tr><td rowspan="2">Quaternary</td><td>Holocene</td><td></td><td>Alluvium</td><td>Missouri and Mississippi rivers and in Mississippi embayment, 500-2000 gpm. Yields are less along smaller rivers.</td></tr>
<tr><td>Pleistocene</td><td></td><td>Loess, till, and other drift, sand and gravel</td><td>Drift and till typically yield 0-5 gpm. Drift-filled preglacial valleys typically yield 50-500 gpm.</td></tr>
<tr><td>Tertiary</td><td>(undifferentiated)</td><td></td><td></td><td>Wilcox Group (Mississippi embayment only), 50-400 gpm.</td></tr>
<tr><td>Cretaceous</td><td>(undifferentiated)</td><td></td><td></td><td>McNairy Formation (Mississippi embayment only), 200-500 gpm</td></tr>
<tr><td>Pennsylvanian</td><td>(undifferentiated)</td><td></td><td></td><td>Northern and west-central Missouri, 1-20 gpm, regionally forms a confining layer.</td></tr>
<tr><td rowspan="5">Mississippian</td><td>Chesterian</td><td></td><td>(undifferentiated)</td><td></td></tr>
<tr><td>Meramecian</td><td></td><td>(undifferentiated)</td><td>Springfield Plateau aquifer</td></tr>
<tr><td>Osagean</td><td></td><td>Keokuk Limestone
Burlington Limestone
Grand Falls Formation
Reeds Spring Formation
Pierson Formation</td><td>Southwest, central, and eastern Missouri, 5-30 gpm.</td></tr>
<tr><td rowspan="2">Kinderhookian</td><td>Chouteau</td><td>Northview Formation
Sedalia Formation
Compton Formation</td><td rowspan="5">Ozark confining unit</td></tr>
<tr><td></td><td>Hannibal Formation</td></tr>
<tr><td>Devonian</td><td>(undifferentiated)</td><td></td><td></td></tr>
<tr><td>Silurian</td><td>(undifferentiated)</td><td></td><td></td></tr>
<tr><td rowspan="3">Ordovician</td><td>Cincinnatian</td><td></td><td>Orchard Creek Shale
Thebes Sandstone
Maquoketa Shale
Cape Limestone</td></tr>
<tr><td>Champlainian</td><td></td><td>Kimmswick Formation
Decorah Formation
Plattin Formation
Joachim Dolomite
Dutchtown Formation
St. Peter Sandstone
Everton Formation</td><td>Ozark aquifer (upper)
Yield is greatest from St. Peter Sandstone. Yields of 5 to 50 gpm are possible.</td></tr>
<tr><td>Canadian</td><td></td><td>Smithville Formation
Powell Dolomite
Cotter Dolomite
Jefferson City Dolomite
Roubidoux Formation
Gasconade Dolomite
Gunter Sandstone Member</td><td rowspan="2">Ozark aquifer (lower)
Yields vary greatly with location and well depth. In Salem Plateau, yields are typically 50-500 gpm. In Springfield Plateau and central Missouri, yields are typically 500 to 1200 gpm.</td></tr>
<tr><td rowspan="3">Cambrian</td><td rowspan="3">Upper Cambrian</td><td></td><td>Eminence Dolomite
Potosi Dolomite</td></tr>
<tr><td>Elvins</td><td>Derby-Doerun Dolomite
Davis Formation</td><td>St. Francois confining unit.</td></tr>
<tr><td></td><td>Bonneterre Formation
Lamotte Sandstone</td><td>St. Francios aquifer.
Yields of 10 to 100 gpm are possible.</td></tr>
<tr><td>Precambrian</td><td>(undifferentiated)</td><td></td><td>Igneous, metasediments, and other metamorphic rock.</td><td>Not a significant aquifer</td></tr>
</table>

[The stratigraphic nomenclature used in this report is that of the Missouri Department of natural Resources, Division of Geology and Land Survey modified after Koenig (1961.]

Table 1. Generalized section of geologic and stratigraphic units (from Vandike, 1993).

OZARKS

The Ozarks region is an uplifted area in southern Missouri and adjacent parts of Arkansas, Illinois and Oklahoma. This region can be subdivided into the St. Francois Mountains, the Salem Plateau, and the Springfield Plateau.

The St. Francois Mountains in southeastern Missouri are the center of the uplift where eroded stumps of a Precambrian mountain range stand in relief, surrounded by younger sedimentary rock. Although it has been a mountain area for more than a billion years, periodic uplift has further increased relief. The highest elevation in the Ozarks, as well as in the state, is in the St. Francois Mountains at the top of Taum Sauk Mountain - an elevation of 1,772 feet msl. The outcrop patterns of younger sedimentary rock units form a rough "bullseye" around the St. Francois Mountains.

The Salem Plateau surrounds the St. Francois Mountains, and is composed of mostly Ordovician and Cambrian age sedimentary rocks. The area is maturely dissected, and consists of steep-sided, deep valleys separated by more gently rolling uplands. Except for upland areas, the modern soils here are typically thin. In upland settings, the bedrock is overlain by thick deposits of unconsolidated residual materials formed from decomposed bedrock. The residuum is typically permeable, which allows high rates of groundwater recharge.

The part of the Ozarks that is underlain by Mississippian age rock is termed the Springfield Plateau. The Salem and Springfield plateaus are separated by the Eureka Springs escarpment. In southwestern Missouri, the Springfield Plateau is generally lower in relief than the Salem Plateau. Depending on location, surface water from the Ozarks drains into the Missouri River, Mississippi River, White River or Arkansas River.

SOUTHEASTERN LOWLANDS

The Ozarks end abruptly along the Ozark escarpment where they abut the Southeastern Lowlands. The Southeastern Lowlands which form the Bootheel area of Missouri, are largely covered by alluvium that was deposited by the St. Francis, Mississippi, and Ohio rivers. The most prominent topographic feature of the Southeastern Lowlands area is Crowley's Ridge, a line of low hills that roughly parallels the Ozark escarpment in the northwestern part of the lowlands. Crowley's Ridge and associated other isolated hills in the lowlands are composed of Tertiary, Cretaceous, and Paleozoic rocks that form islands in the alluvial materials that surround them. The lowest elevations in Missouri are in the Southeastern Lowlands. The lowest point in Missouri is on the Little River at the Arkansas border where the elevation is about 230 feet msl.

Drainage patterns in the Southeastern Lowlands have been drastically altered during the past century. Formerly, the Bootheel was noted for its swamps and poor drainage. Drainage projects, beginning in the late 1800s and continuing well into this century, diverted water entering the Bootheel from the north directly into the Mississippi River. The projects also divered water between the Mississippi and St. Francis Rivers into a series of south-flowing drainage ditches that channel the water south into Arkansas and, finally, into the Mississippi River.

PHYSIOGRAPHIC AND GEOLOGIC EFFECTS ON WATER RESOURCES

The effects of geology and physiography on Missouri surface water resources are pronounced. For example, the glacial till of northern Missouri has a very low permeability, therefore, infiltration is low and runoff is rapid. The low permeability and lack of groundwater inflow into streams makes for very low base flows during dry weather. Furthermore, northern Missouri is extensively row-cropped for the production of corn, soybeans and other grains, and glacial till is easily eroded, especially on steeper slopes. This combination leads to high suspended sediment loads in many streams and rivers.

Conditions are nearly the opposite in the Ozarks. Here, because of topography, thin soils, and poor soil fertility, row cropping is mostly limited to the floodplains of major streams and rivers. Thus, there is much lower soil loss due to erosion. Most streams in southern Missouri receive considerable groundwater from springs and general groundwater inflow, so even during dry weather they have well-sustained base flows.

A comparison of hydrologic characteristics of similar size basins in northern and southern Missouri shows how geologic factors, to a great extent, control basin runoff.

The **North River** at *Palmyra*, an upper Mississippi River tributary, drains 373 square miles. Glacial till covers the bedrock surface throughout most of the basin, and the till is underlain by Mississippian-age sedimentary rocks. Average discharge of the North River, based on 60 years of records, is 264 ft^3/sec, or an average annual runoff rate of about 9.61 inches.

The **Jacks Fork** at *Eminence*, a **Current River** tributary in the Salem Plateau of the Ozarks, has a similar drainage area, 398 square miles. Based on 73 years of record, average discharge here is 457 ft^3/sec, or about 15.6 inches. Most of the difference in the amount of runoff can be attributed to rainfall. Average annual rainfall in the North River basin is about 36 inches, while the Jacks Fork receives about 42 inches per year, a difference of 6 inches. However, differences in the low-flow characteristics of the two streams are due to geology. Figure 3 is a flow-duration curve of both rivers. It illustrates the differences in low-flow discharge. Flow of the North River is greater than 3.2 ft^3/sec about 90 percent of the time, but there are numerous times when there has been no flow in the stream. The lowest recorded flow for the Jacks Fork River is 64 ft^3/sec, and 90 percent of the time the flow exceeds 123 ft^3/sec.

The **North River** basin is underlain by low-permeability glacial drift that does not release enough groundwater to maintain flow during dry weather. The **Jacks Fork** is precisely the opposite. Its basin is characterized by large springs developed in permeable Cambrian- and Ordovician-age dolomites. The springs are recharged from sinkholes, losing streams, and general infiltration through the permeable residuum that covers most of the area. Much of the water that would ordinarily run off into streams is channelled underground through losing streams and sinkholes. The water is then slowly released from storage by the aquifer through springs, which helps to maintain the high base flow of the stream.

In most of northern Missouri and the Osage Plains, surface water and groundwater can be considered separate resources. In the Ozarks, however, it is neither logical nor desirable to always consider surface water and groundwater as separate entities.

The Ozarks is mostly underlain by dolomite and limestone formations that have been greatly affected by weathering, both at land surface and in the subsurface. Solutional weathering of the bedrock has created well-integrated subsurface drainage systems that capture surface water and channel it underground. Water is carried underground through losing streams and sinkholes, and transported through cave-like openings to springs where the water surfaces. A losing stream is one which loses most or all of its normal flow into the subsurface. Sinkholes are topographic depressions formed by the subsurface removal of soil and rock. Both sinkholes and losing streams funnel large volumes of surface water into the subsurface.

In much of the Ozarks, surface water goes underground in losing streams and sinkholes, thereby providing rapid groundwater recharge. Rapid infiltration of rainfall through the permeable surficial materials is also an important source of groundwater recharge. The water generally returns to the surface at springs and again becomes surface water. In places, this cycle may be repeated two or more times before the water enters a stream with permanent flow. This interaction between surface water and groundwater is widespread throughout the Ozarks, and groundwater movement is rapid. Springs, caves, sinkholes, and other karst features so common in the Ozarks are not present in most other areas of the state. Most groundwater recharge in other parts of Missouri is by relatively slow downward movement of water from precipitation into shallow aquifers.

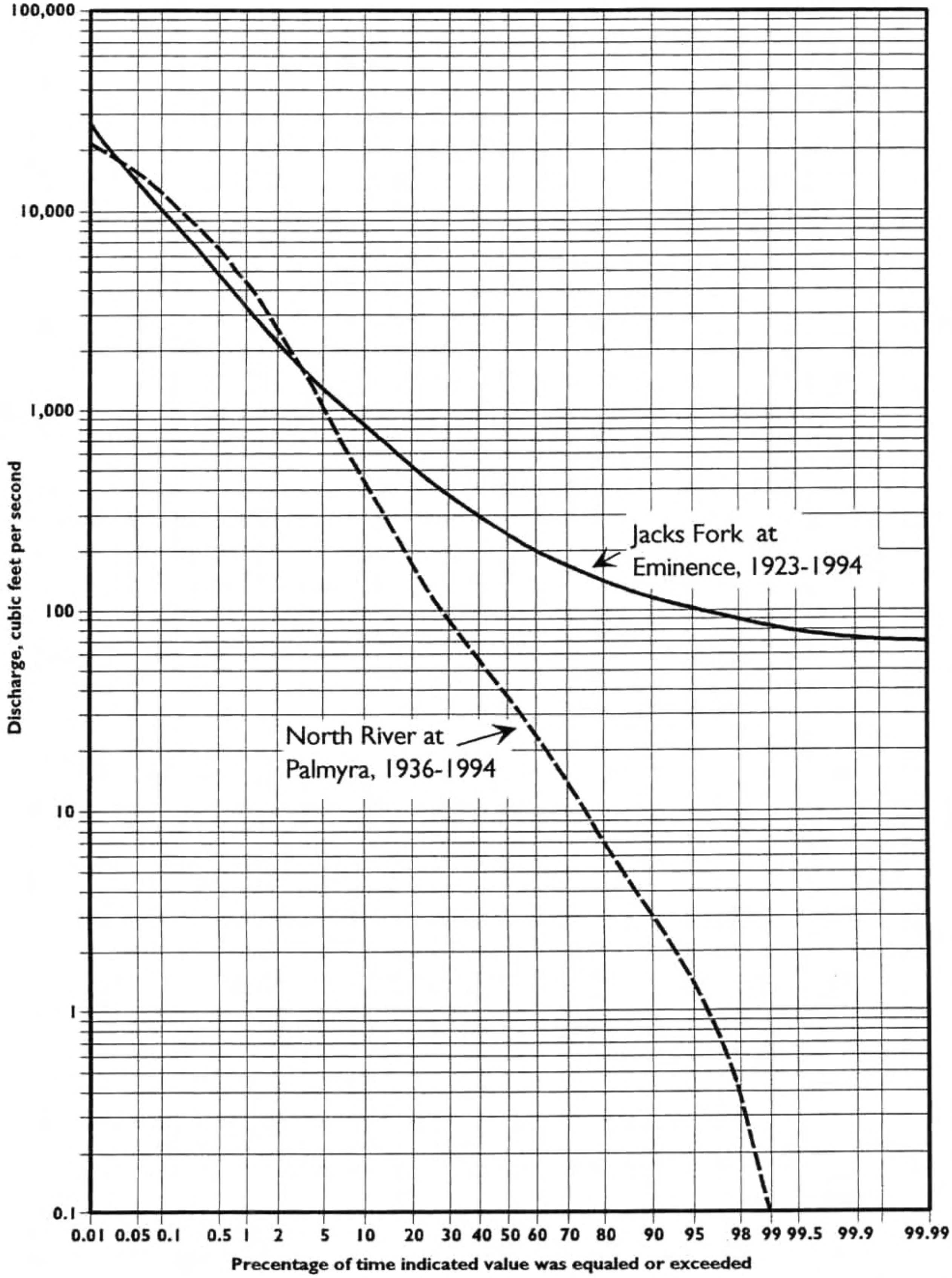

Figure 3. Flow-duration curves, Jacks Fork at Eminence and North River at Palmyra.

THE HYDROLOGIC CYCLE

Although the distribution of water changes over time and from place to place, as evidenced by flooding and drought, the total volume of water does not change. There is a continuous interchange of water from ocean to atmosphere to land surface--a never-ending hydrologic cycle that is powered by solar heat (figure 4).

Water enters the atmosphere from ocean and land-mass evaporation, and plant transpiration. The losses due to evaporation and transpiration are generally combined and referred to as evapotranspiration. Water vapor in the atmosphere condenses, and returns to the Earth's surface through precipitation.

Much of the water supplied from precipitation is evaporated back into the atmosphere

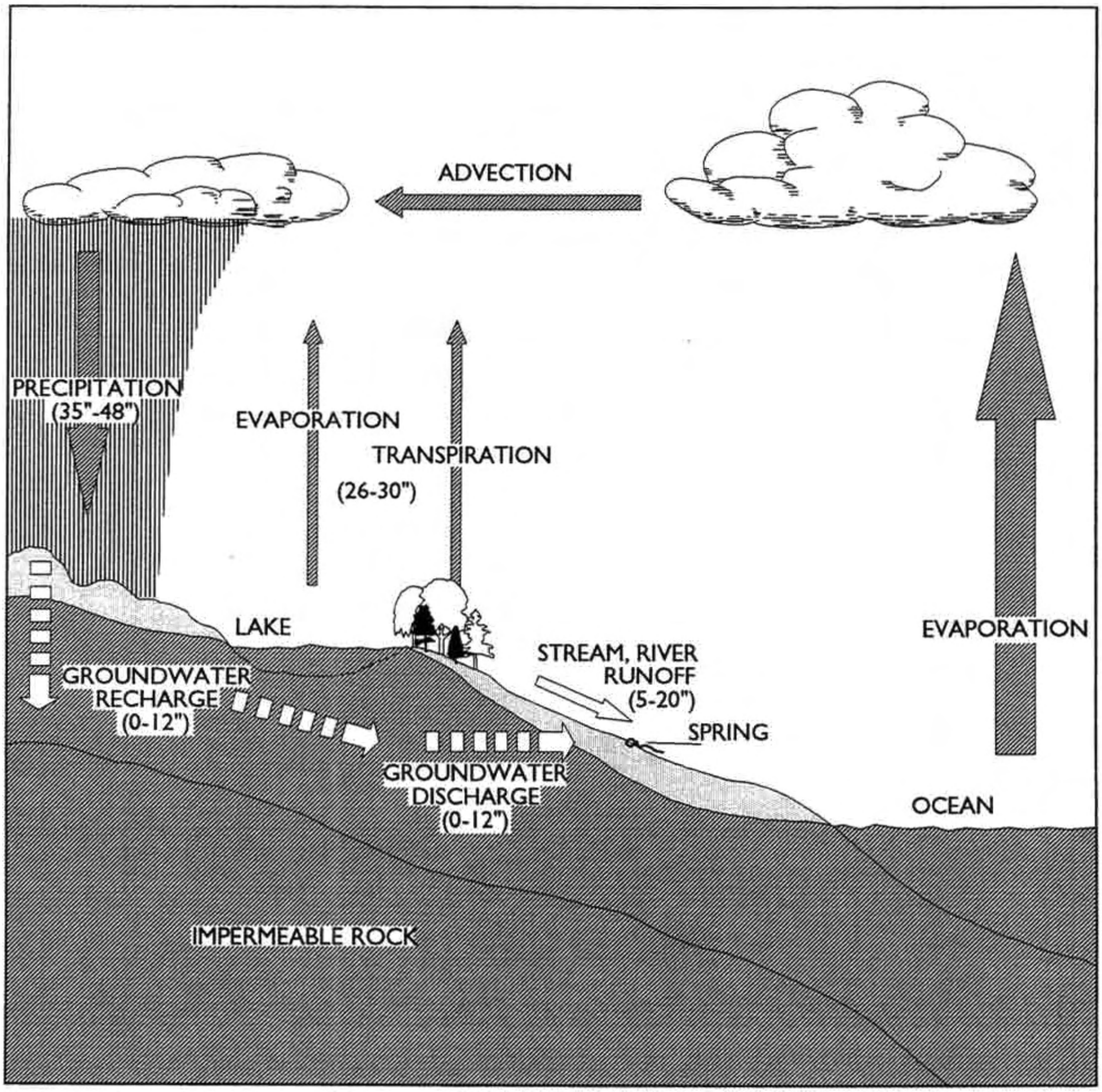

Figure 4. The hydrologic cycle showing the approximate range of average annual precipitation, evapotranspiration and runoff in Missouri.

or is used by plants and returned to the atmosphere. If precipitation is heavy or soils are already saturated, surface-water runoff occurs and the water enters streams and lakes, eventually returning to the atmosphere or ocean. Depending on geologic conditions, the remaining water from precipitation enters the subsurface and recharges groundwater supplies. Eventually, most of it is returned to the Earth's surface as spring flow or general groundwater inflow into streams and rivers. The average annual amounts of precipitation, evapotranspiration, runoff, and groundwater recharge and discharge, are also shown in figure 4.

Temperature and Precipitation

Missouri has a humid, continental climate with an average temperature of about 55°F. Average annual temperature ranges from a low of about 51°F in the northwestern corner of the state to a high of about 59°F in the Bootheel. Rainfall in Missouri has a much greater variation, normally lowest in the northwestern corner of the state and highest in the southeast.

More than one hundred years of temperature and rainfall data are available from some weather stations in Missouri. A plot of average annual precipitation containing data from all observation stations in Missouri with at least 40 years of record is shown in figure 5. Based on these data, mean annual rainfall ranges from less than 35 inches in northwestern Missouri to about 48 inches in the Bootheel, with a statewide average of about 38 inches. Average seasonal precipitation is shown in figure 6. Highest rainfall amounts are generally during spring months, and the lowest are in the fall and winter. Rainfall during June, July, and August, in the peak of the growing season, normally ranges from 11 to 13 inches statewide. Despite this, high temperatures during the same period often deplete soil moisture storage and lead to deficiencies in moisture for crops and vegetation.

Although precipitation in Missouri is normally sufficient for most needs, climatic extremes occur all too frequently. Figures 7 and 8 show Missouri precipitation during 1956 and 1957. In 1956, much of the state was still suffering from an extended drought. Rainfall was low in much of central and northern Missouri while parts of south-central Missouri had near-normal amounts. The following year, part of northwest Missouri was still dry, but yearly rainfall amounts as high as 90 inches were recorded in southeast Missouri. For northern Missouri, 1988 was one of the driest years on record. Many areas received less than one-half of the normal rainfall (figure 9). Most of the remainder of the state, though, had average or above average rainfall.

Missouri has suffered several periods of major drought during this century. Based on the discharge records of major rivers, northern Missouri had the worst drought conditions during the early 1930s. Most rivers here had their lowest average annual flow in water year 1934. In the southern part of the state the early 1950s were very dry. Water year 1954 was the lowest flow year on record for many rivers in southern Missouri.

The year 1993 will, undoubtedly, be remembered as one of the wettest years for Missouri. Rivers in much of the state had record peak flows as well as record yearly flows. Precipitation throughout most of the state was above normal (figure 10). Northwest Missouri, normally the driest area, had nearly twice as much precipitation as normal. Parts of east-central and southwest Missouri had yearly precipitation that exceeded 70 inches. Southeastern Missouri, normally the wettest area in the state, was one of the driest areas in 1993. While in many areas of Missouri residents were sandbagging levees to control flooding, farmers in the Bootheel were irrigating because of locally dry conditions. For many Ozark streams, water year 1985 was the year of highest flow.

Evapotranspiration

Although precipitation is the ultimate source of the water resources base, not all of the water from precipitation is available for use. On average, about 28 inches of Missouri's average 38 inches of precipitation is lost to evapotranspiration. Average annual evapotranspiration rates varies from about 26 inches in extreme northern Missouri to about 30 inches in southeastern Missouri (figure 11). Statewide, the remaining 10 inches, or about 26 percent of the precipitation, becomes runoff.

RUNOFF

Average annual runoff rates range from about 5 inches in northwestern Missouri to about 20 inches in the Southeastern Lowlands (figure 12). In the Ozarks, much of what is shown as surface-water runoff includes groundwater inflow into streams. Here, numerous losing streams and sinkholes channel large quantities of water into limestone and dolomite aquifers. Most of the water is returned to the streams and rivers at springs. The amount of groundwater underflow, which leaves the area, is comparatively minor.

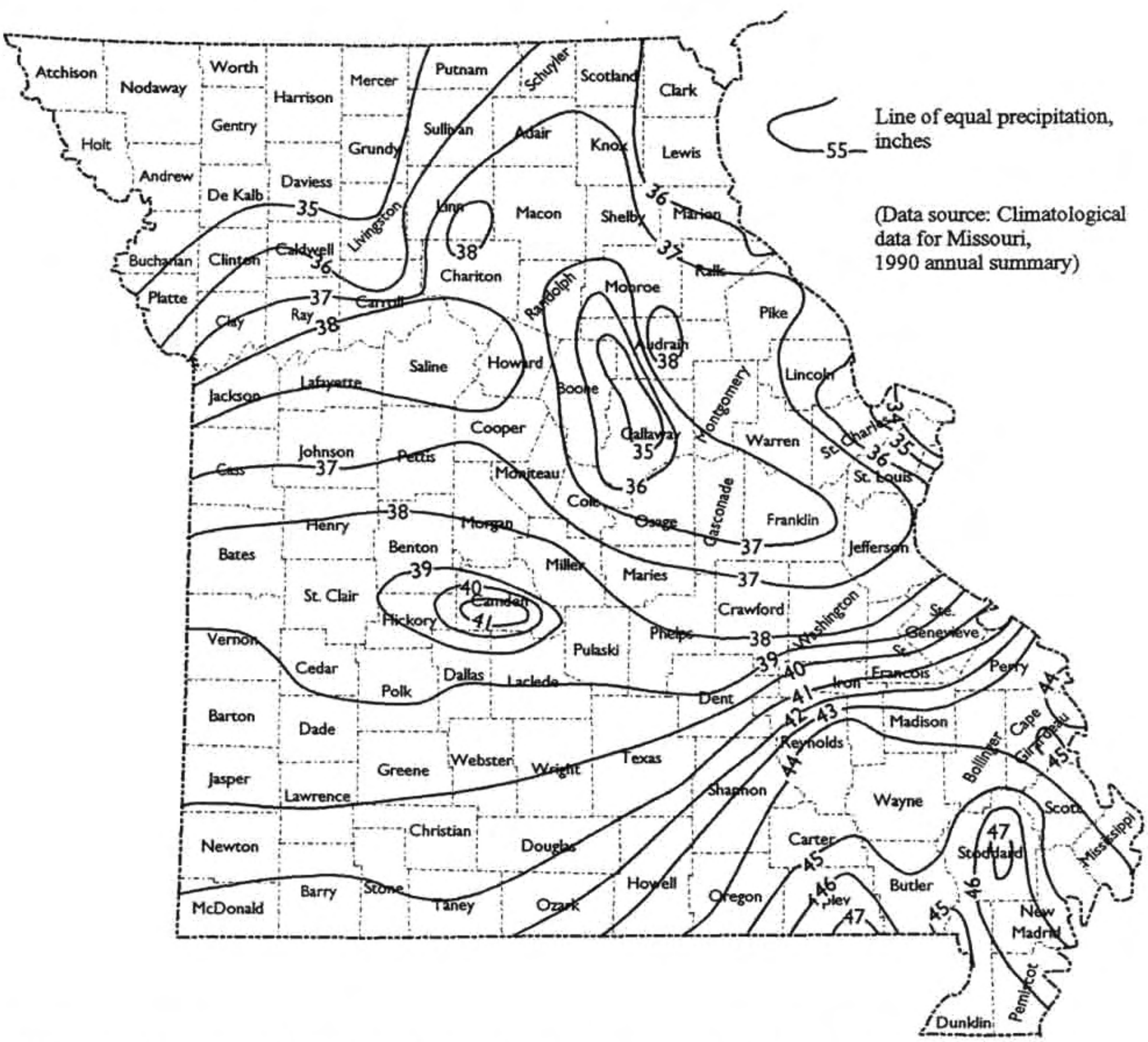

Figure 5. Long-term average annual precipitation based on stations with 40 or more years of data ending 1990.

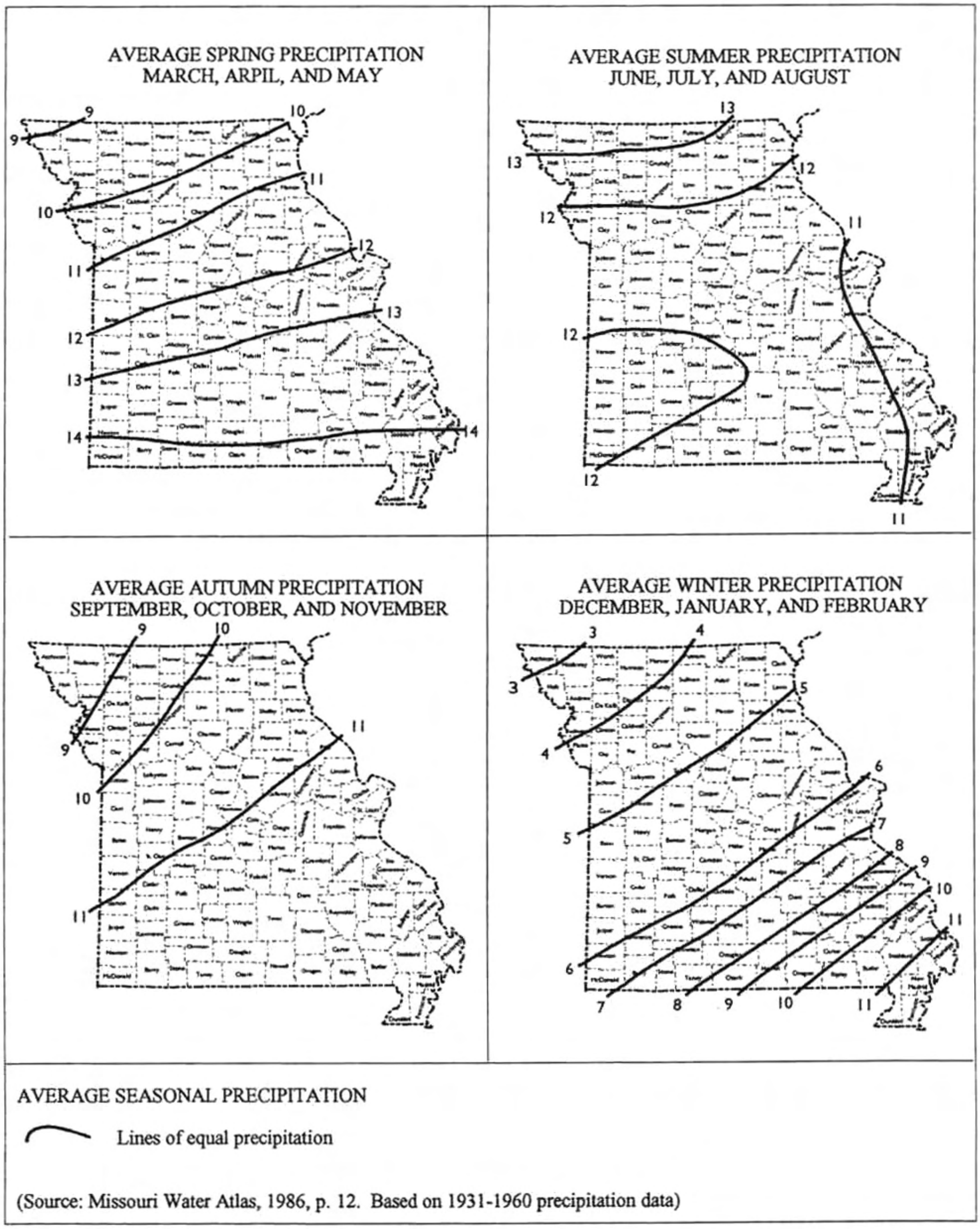

Figure 6. Seasonal precipitation.

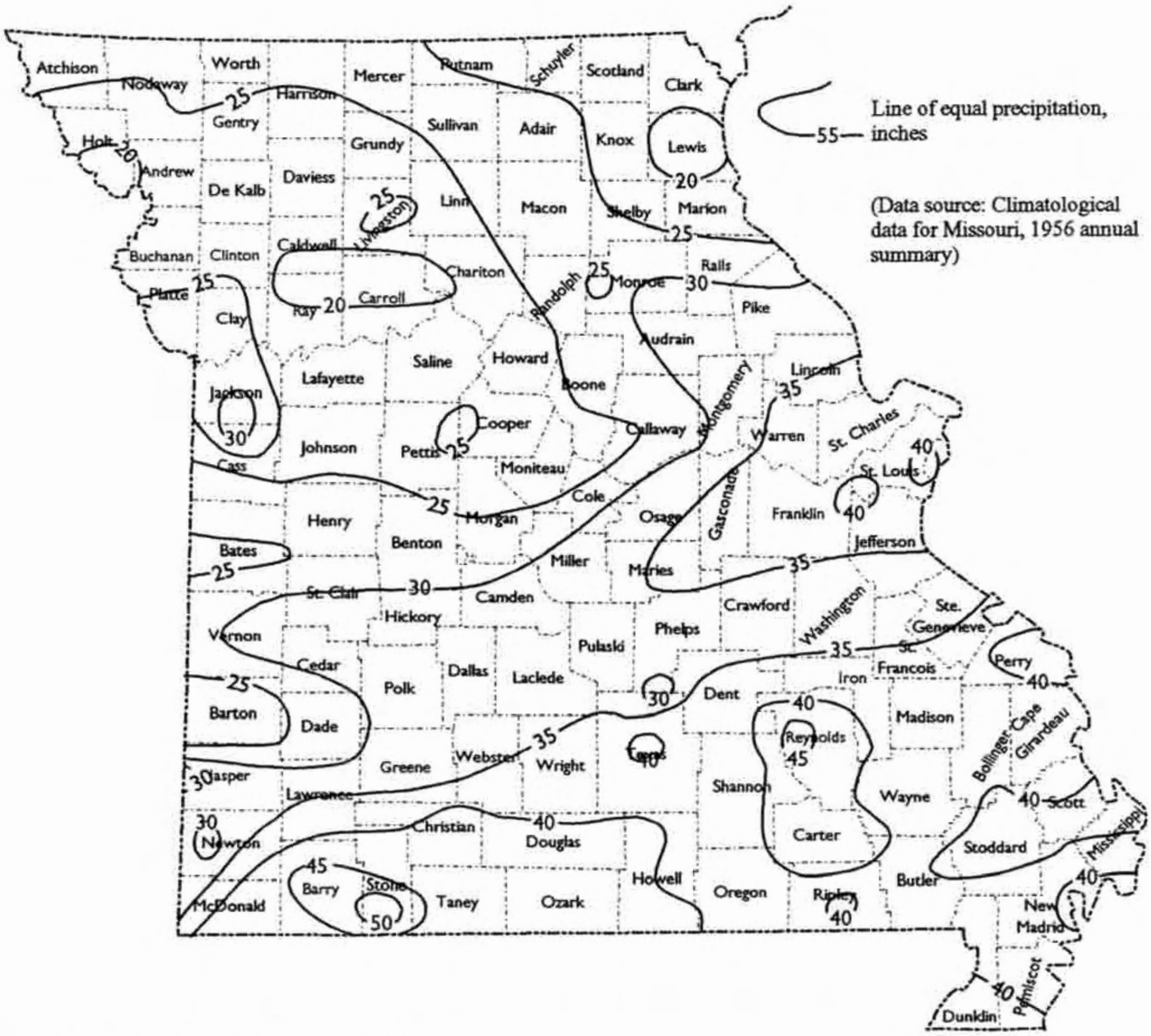

Figure 7. Precipitation in Missouri, 1956.

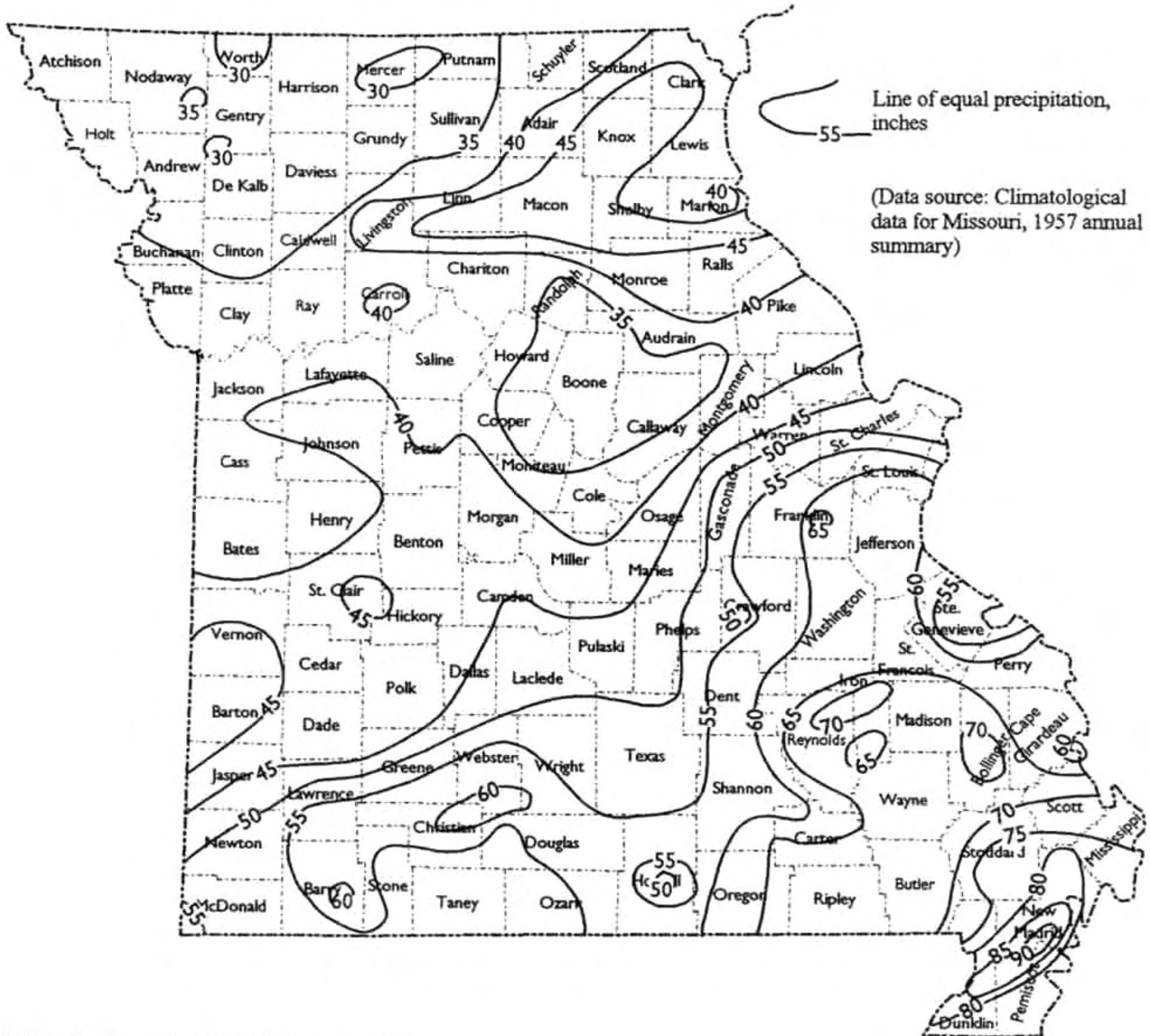

Figure 8. Precipitation in Missouri, 1957.

Figure 9. Precipitation in Missouri, 1988.

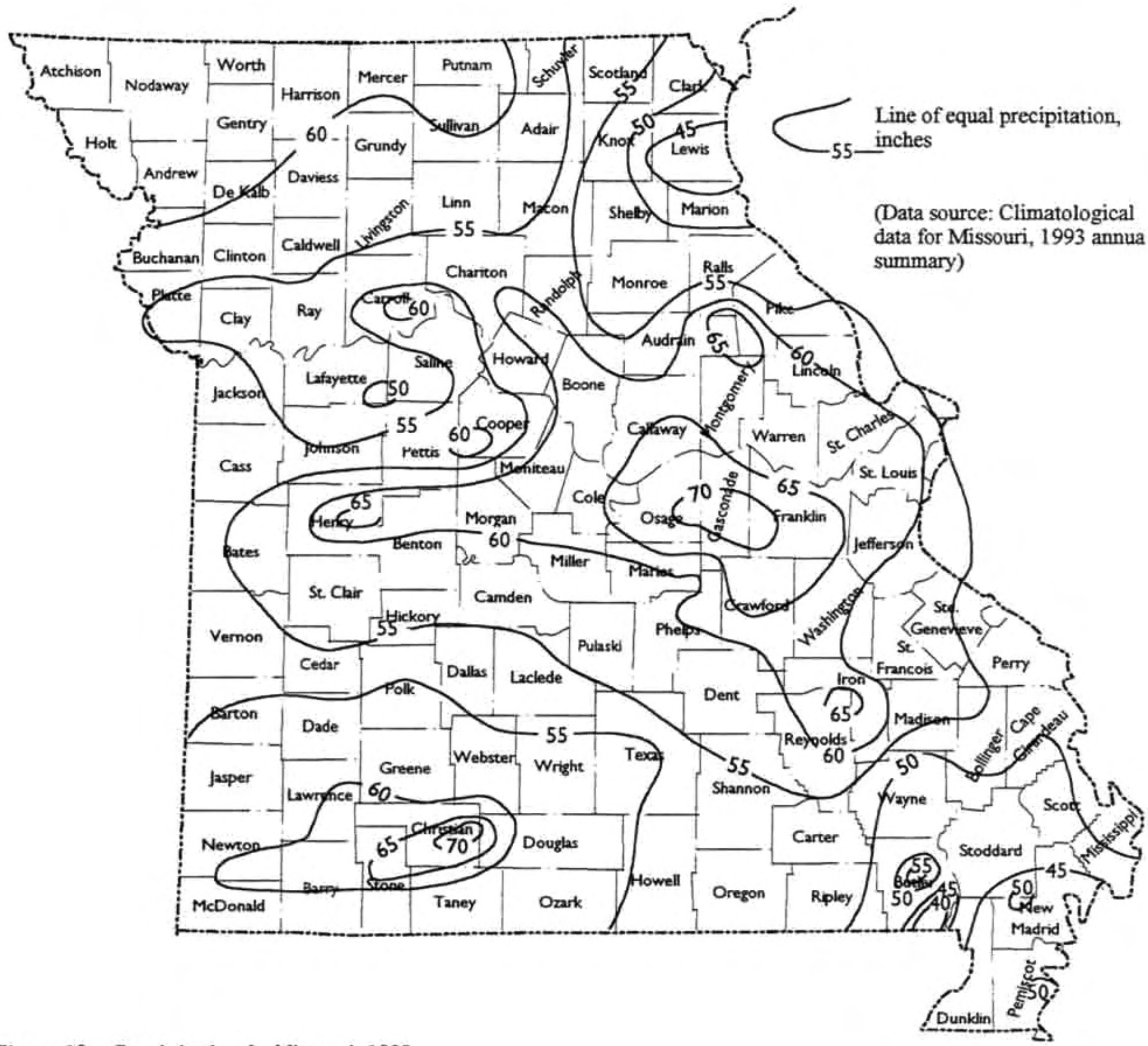

Figure 10. Precipitation in Missouri, 1993.

Figure 11. Estimated annual evapotranspiration losses based on 1931-1960 runoff and precipitation data.

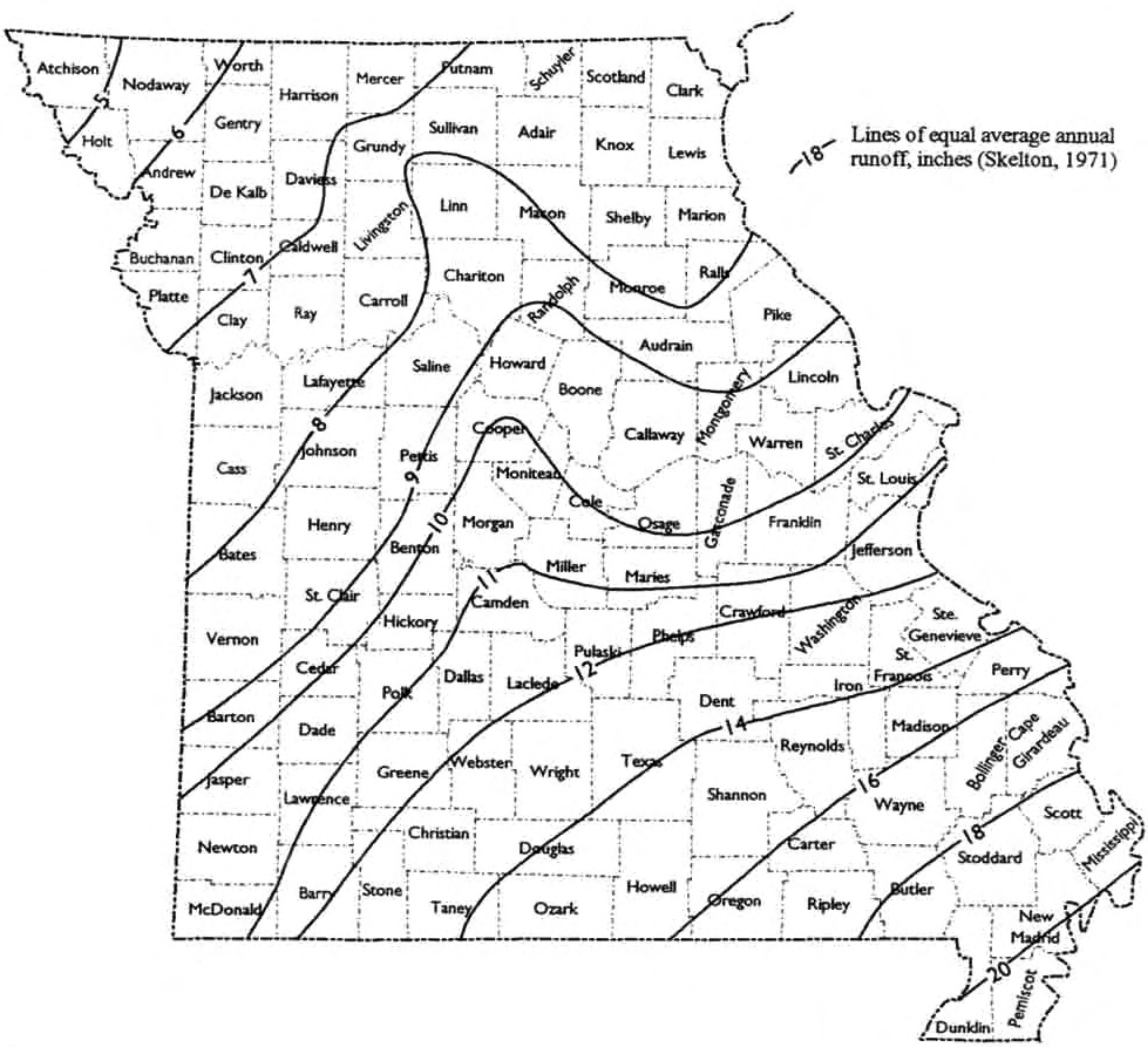

Figure 12. Average annual runoff in Missouri.

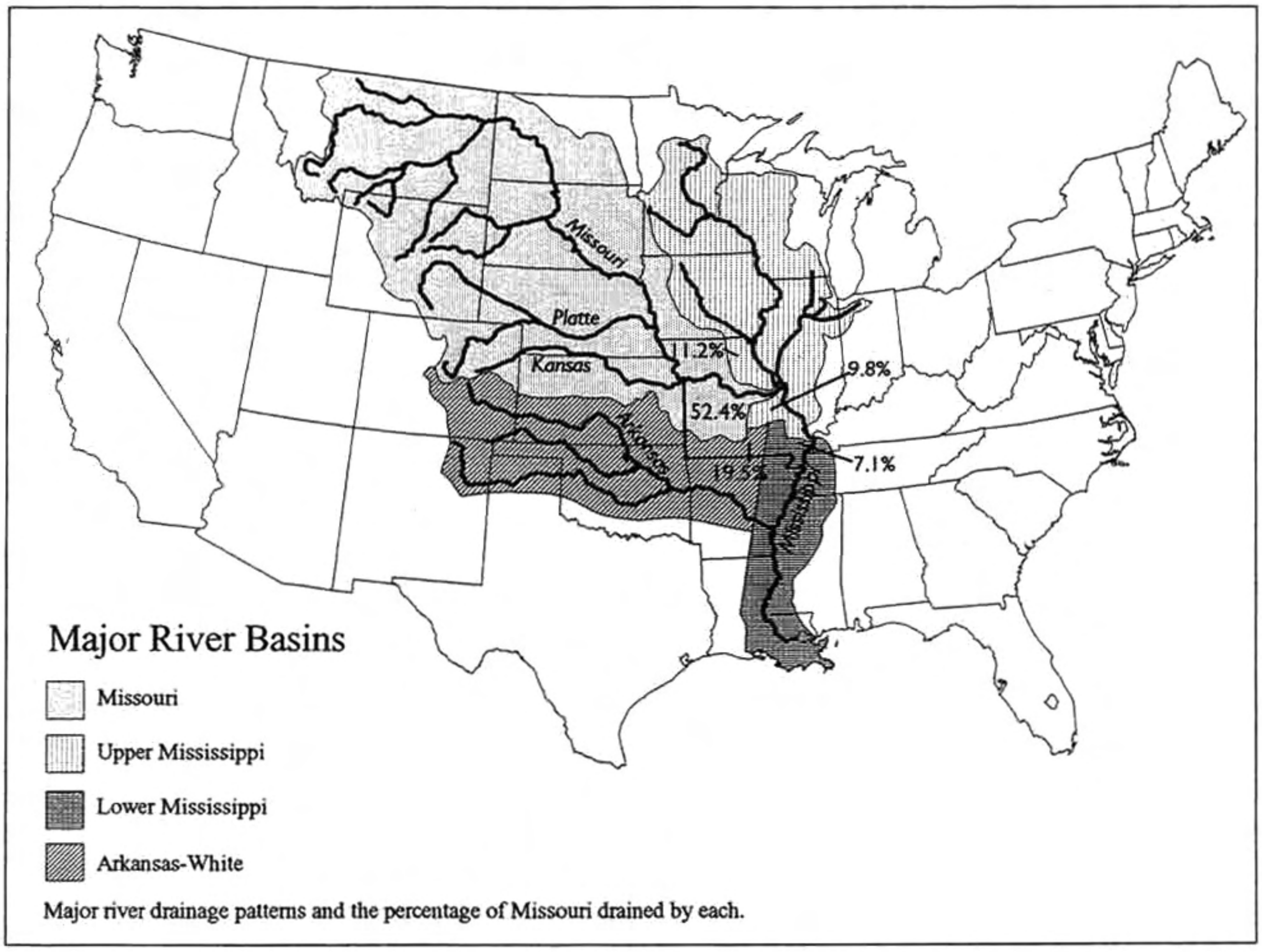

Figure 13. Major river basins in the Midcontinent region.

GENERAL SURFACE WATER RESOURCES OF MISSOURI

All of Missouri drains directly or indirectly into the ***Mississippi River***. Upstream from St. Louis, about 7,789 square miles, (11.2 percent of the total area of the state) drains directly into the Mississippi River. Downstream from St. Louis and upstream from the ***Ohio River***, another 6,850 square miles (9.8 percent of the state) drains into the Mississippi. About 4,975 square miles (7.1 percent of Missouri) flows into northern Arkansas and into the Mississippi River. Another 13,547 square miles (19.4 percent of the state) drains into the ***White*** and ***Arkansas rivers***. The remaining 52.4 percent of the state, about 36,537 square miles, drains into the ***Missouri River*** (figure 13).

Based on an average annual runoff rate of 10 inches, surface water from precipitation originating in Missouri each year averages about 37 million ac-ft, or about 12 trillion gallons. Another 30 million ac-ft (9.8 trillion gallons) enters the state from the ***Missouri River***. The upper ***Mississippi River*** contributes an additional 85.5 million ac-ft (27.8 trillion gallons). Not counting relatively minor contributions from streams flowing into Missouri from Iowa and Kansas, the above total equals about 152.5 million ac-ft (nearly 50 trillion gallons).

The ***Missouri River*** drains a total area of about 529,000 square miles, of which about 36,537 square miles (about 6.9 percent) lies in Missouri. Despite the relatively small amount of Missouri River drainage area that is in Missouri, runoff from Missouri contributes greatly to the flow of the Missouri River within the state. The average discharge of the Missouri River at *Kansas City*, based on data collected from 1897 through 1993, is 50,850 ft^3/sec. Data collected during the same time interval at *Hermann* shows that the average discharge of the Missouri River at Hermann is 78,400 ft^3/sec. Flow of the Missouri River between Kansas City and Hermann increases an average of 27,550 ft^3/sec (about 54 percent).

On the average, about 65 percent of the flow of the ***Missouri River*** at *Hermann* is provided by runoff from states upstream from Missouri, while 35 percent of the water is provided by the state itself. These values are only approximate, but they show the importance that runoff in Missouri has on the flow of the river within the state. In the above figures, runoff from the ***Nodaway*** and ***Platte rivers*** were included with that of upstream states. Runoff from Iowa through the ***Grand*** and ***Chariton rivers***, and from Kansas in the upper ***Osage*** basin, were included with runoff in Missouri.

An examination of the discharge records of the ***Missouri River*** shows that, despite its large drainage area, the Missouri River basin upstream from Missouri has a very low runoff rate. The Missouri River upstream from *Rulo*, Nebraska, near the northwestern tip of Missouri, drains an area of about 414,900 square miles. The average discharge of the river at *Rulo*, based on 44 years of record keeping, is only about 41,180 ft^3/sec. This is a runoff rate of only about 1.35 inches. Annual runoff of the Missouri River at *Hermann* is about 2.03 inches.

Several factors contribute to the low runoff rate of the Missouri River basin. Precipitation in most of the Missouri River basin, compared to that in the state of Missouri, is quite low, less than 15 inches in many areas. The Missouri River is nearly a continuous reservoir from Gavins Point Dam in southeastern South Dakota to ***Oahe Reservoir*** in North Dakota. Evaporation from these reservoirs is greater than the flows of many small rivers.

The ***Mississippi River*** upstream from the Missouri River drains a much smaller area than the Missouri but has a much higher runoff rate and annual discharge. Upstream from *Grafton*, Illinois, which is 23 miles upstream from the confluence with the Missouri, the Mississippi River drains an area of about 171,300 square miles. The average discharge of the river here is 122,800 ft^3/sec (9.74 inches). The drainage basin is less than one-third the size of the Missouri River basin, but discharge is 92,900 ft^3/sec or 56 percent greater.

There are dozens of smaller river and stream basins in the state that contribute greatly to the overall water resources of Missouri. A 1968 survey by the Missouri Department of Conservation inventoried 18,077 miles of streams in the state showing that about 9,865 miles of stream contained permanent flow, and 8,212 miles have intermittent flow and permanent pools. Though not specified, there are undoubtedly several thousand miles of additional streams with lesser flows.

There are numerous surface-water impoundments in Missouri. They range in size

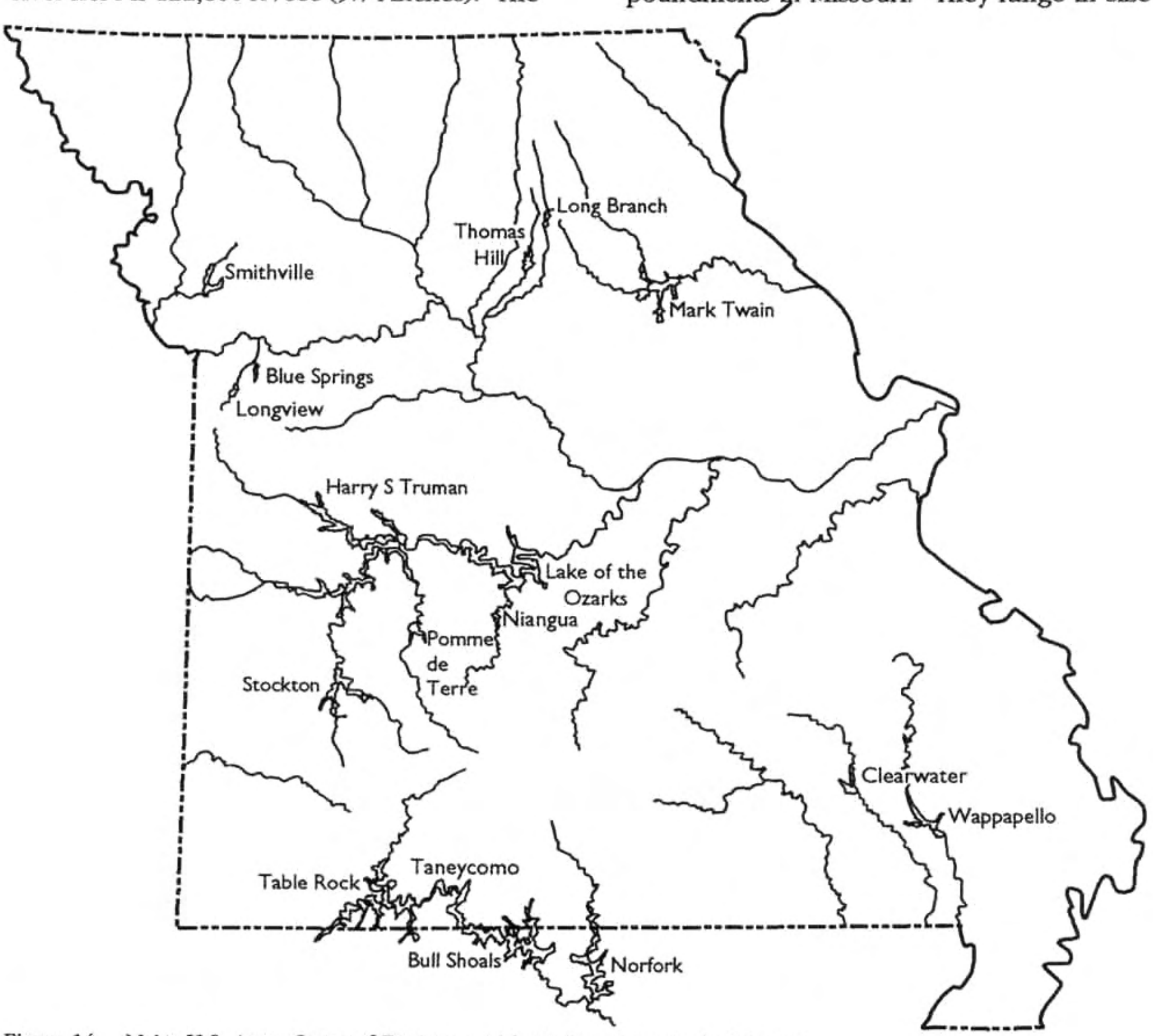

Figure 14. Major U.S. Army Corps of Engineers and private reservoirs in Missouri.

from farm ponds less than one acre in size, to Lake of the Ozarks, which has a surface area at normal pool level of 55,600 acres. All or parts of 13 major U.S. Army Corps of Engineer impoundments are in Missouri (figure 14 and table 2). At normal pool levels, these reservoirs impound 10,080,700 ac-ft of water (about 3.29 trillion gallons). There are also 4 major privately owned reservoirs in the state with a combined total storage of 1,997,575 ac-ft. Combined, all of these major reservoirs impound more than 12 million ac-ft, holding enough to cover the entire state with 3.2 inches of water (Atlas, 1986).

These large impoundments are only a few of the total number of reservoirs in the state. In 1980, an inventory was made of all dams in Missouri that were at least 6 feet in height and impounded more than 50 ac-ft of water, or were at least 25 feet high and impounded more than 15 ac-ft of water. The inventory found a total of 3,240 dams in Missouri that fit these criteria, including 85 that are federally owned or controlled. Since 1980, approximately 733 more dams of this size have been built, and the total number of lakes is now estimated to be 3,973 (Alexander, 1995; personal communication).

The vast majority of the ponds and lakes in Missouri are privately owned and used for agricultural or recreational purposes. The Department of Natural Resources regulates

Reservoir	Stream Dammed	Date of Completion	Length of Dam (ft)	Dam Height above Streambed (ft)	Elevation of Top of Dam (ft above M.S.L.)	Elevation of Flood-Control Pool (ft above M.S.L.)	Elevation of Muiltiple-Purpose (Conservation) Pool (ft above M.S.L.)	Flood-Control Storage (acre-feet)	Multiple-Purpose (Conservation) Storage (acre-feet)	Surface Area of Flood Control Pool (acres)	Surface Area of Multiple-Purpose (Conservation) Pool (acre-feet)	Lenght of Shoreline of Flood-Control Pool (miles)	Lenght of Shoreline of Multiple-Purpose (Conservation) Pool (miles)
U.S. Army Corps of Engineers													
Wappapello	St. Francis	1941	2,700	109	417	395	355-360[a]	613,000	30,900-62,800[a]	23,200	4,100	----	180
Clearwater	Black	1948	4,225	154	608	567	494-498[a]	413,000	22,000	10,350	1,630	172	27
Norfork[b]	North Fork	1944	2,624	216	590	580	550-554[a]	1,983,000	1,251,000	30,700	22,000	510	380
Bull Shoals[b]	White	1952	2,256	256	708	695	654	5,408,000	3,048,000	71,240	45,440	1,050	740
Table Rock	White	1959	6,423	252	947	931	915	3,462,000	2,702,000	52,300	43,100	857	745
Stockton	Sac	1973	5,100	153	912	892	867	1,674,000	875,000	63,200	24,900	----	298
Pomme de Terre	Pomme de Terre	1963	7,240	155	905	874	839	407,000	243,000	16,100	7,820	----	113
Harry S Truman	Osage	1979	5,000	126	756	740	706	3,999,300	1,202,700	209,300	55,600	----	958
Longview	Little Blue	1982	1,900	110	927	909	891	46,900	22,600	2,890	930	----	24
Blue Springs	East Fork Little Blue	1982	2,500	57	835	814	794	21,600	5,600	940	560	----	13
Smithville	Little Platte	1979	4,000	75	895	876	864	246,500	154,000	17,190	7,190	----	175
Long Branch	East Fork Chariton	1979	3,800	71	826	801	791	65,000	35,000	6,100	2,430	----	24
Mark Twain	Salt	1983	1,940	138	653	638	606	1,428.000	457,000	38,400	18,600	----	285
Private													
Lake of the Ozarks (Union Electric Co.)	Osage	1931	2,543	148	670	----	660	----	1,927,000	----	60,000	----	1150
Niangua (Show Me Power Co.)	Niangua	1931	850	20	711	----	771	----	1,200	----	300	----	12
Taneycomo (Empire District Electric Co.)	White	1912	1,265	50[c]	----	----	701[d]	----	9,175	----	2,100	----	53
Thomas Hill (Associated Electric Coop.)	Middle Fork Chariton	1967	3,000	77	737	715	703	83,500	60,200	5,400	4,800	----	70

[a]Varies with month of the year
[b]Dam is in Arkansas
[c]Varies with elevation of Bull Shoals Lake
[d]Varies with release of water from Table Rock Lake

Table 2. Physical data for major reservoirs in Missouri.

most non-federal dams greater than 35 feet in height through its Dam and Reservoir Safety Program. The department currently regulates 560 dams greater than 35 feet in height. Dams and reservoirs used for agricultural purposes in Missouri are not regulated. There are about 38 agricultural dams greater than 35 feet in height in the state.

As of 1991, 123 reservoirs in Missouri were being used for public water supply (DEQ, 1991). Most of these are owned by the cities that they serve, but several are U.S. Army Corps of Engineer reservoirs. Some of the reservoirs serve more than one town, while other towns use more than one reservoir. About 25 of these water-supply reservoirs are supplemented by pumping from a stream or river.

The number of lakes by county that are used for public water supply are shown in figure 15. Also shown is the fresh water-saline groundwater transition zone. South of the zone, deep aquifers that yield large quantities of water contain water that requires little or no treatment before use. North of the zone the same aquifers contain highly mineralized water that, without extensive treatment, is unsuitable for most uses. As can be seen from figure 15, most of the public water supply reservoirs serve areas where productive aquifers contain highly mineralized water.

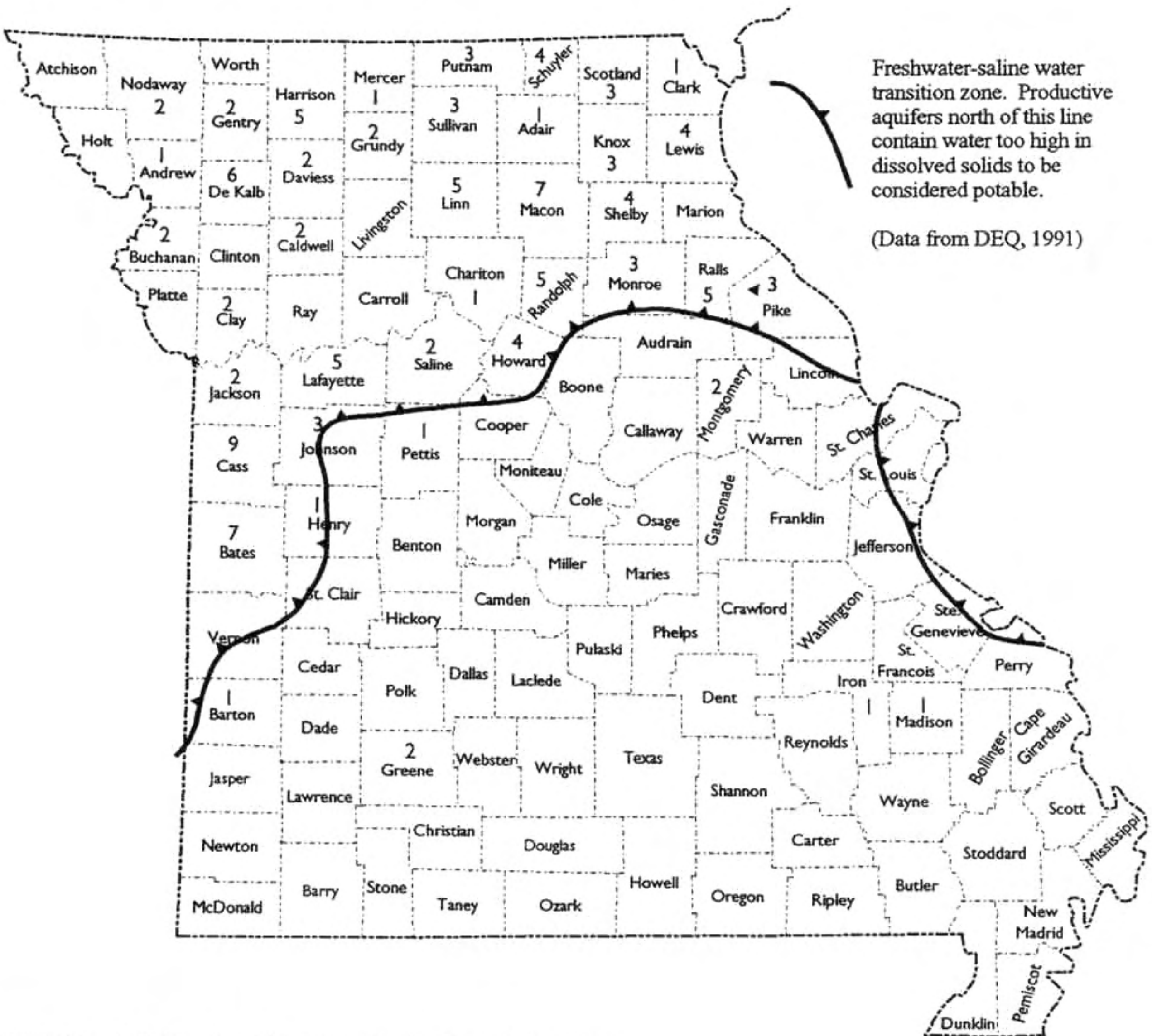

Figure 15. Number of public water supply reservoirs by county.

The Missouri Department of Conservation and Missouri Department of Natural Resources also have several lakes in the state that are important recreational resources. Table 3 gives the names, locations, and other information for 26 of these lakes.

It is difficult to accurately estimate the number of small ponds in the state. However, the state has a surface area of 69,709 square miles. Assuming there are five ponds per square mile, then there are approximately 350,000 ponds in Missouri. If each holds an average of 3 ac-ft of water, it means that more than one million ac-ft of water is stored in Missouri ponds. Statewide, these smaller ponds are important sources of water for livestock, fish, wildlife and recreation.

Lakes and reservoirs in Missouri are an important asset to the water resources of the state. In northern Missouri, where even major rivers have very low flows during dry weather, impoundments are the only way to ensure

Name of Lake	Agency (1-2)	County	Location Sec.	Twn.	Rng.	Surface Area (ac)	Drainage Area (ac)
Harmony Mission	(1)	Bates	15	38	32W	96	1520
Ben Branch	(1)	Osage	15	44	8W	44	625
Manito	(1)	Moniteau	8	44	17W	876	1480
Fox Valley	(1)	Clark	27	66	8W	108	1135
Busch Wildlife #35	(1)	St. Charles	19	46	2E	54	2131
Lake Paho	(1)	Mercer	25	65	25W	275	2950
Lake Lincoln	(2)	Lincoln	8	49	1E	88	960
St. Joe State Park	(2)	St. Francois	18	36	5E	278	3176
Nodaway Lake	(1)	Nodaway	20	65	35E	73	730
Finger Lakes South	(2)	Boone	30	50	12W	48	740
Little Dixie	(1)	Callaway	26	48	11W	200	2314
Blind Pony	(1)	Saline	18	49	27W	95	3255
Bushwhacker	(1)	Vernon	26	34	32W	157	2650
Lake Girardeau	(1)	Cape Girardeau	9	30	11E	147	1984
Binder	(1)	Cole	36	45	13W	150	3860
Pony Express	(1)	DeKalb	33	58	31W	281	2900
Henry Sever	(1)	Knox	14	60	10W	158	2800
Deer Ridge Comm.	(1)	Lewis	18	62	8W	48	600
Perry Co. Comm.	(1)	Perry	22	35	10E	87	2560
Little Prairie	(1)	Phelps	21	38	7W	100	1540
Tywappity Comm.	(1)	Scott	8	29	13E	43	362
Hunnewell	(1)	Shelby	25	57	9W	208	2560
Indian Cr. Comm	(1)	Livingston	27	59	25W	192	3580
Hazel Hill Comm.	(1)	Johnson	27	47	26W	71	1500
Bilby Ranch WA	(1)	Franklin	16	43	3W	55	1040

(1) = Lake owned by Missouri Department of Conservation
(2) = Lake owned by Missouri Department of Natural Resources

(Data source: DNR-Dam and Reservoir Safety Program)

Table 3. Lakes owned by the Missouri Department of Conservation and the Missouri Department of Natural Resources.

an ample supply of water during drought. Evaporation is a major loss from reservoirs. Lake-surface evaporation in Missouri ranges from about 36 inches in northeastern and eastern parts of the state to about 46 inches in the southwestern corner (figure 16). Evaporation during May through October, accounts for 74 to 78 percent of the annual amounts. The 17 major Corps of Engineers and private reservoirs in the state have a combined surface area of about 301,500 acres (471 square miles). Yearly evaporation losses from these reservoirs is about 980,000 ac-ft, (319 billion gallons). This amounts to an average loss of 1,353 ft³/sec, which is approximately the average long-term flow of the ***Meramec River*** near *Sullivan*.

Numerous rivers and streams located primarily in northern and western Missouri are also used for municipal water supply. Of the 55 surface water intakes, 11 produce from the ***Missouri River***, five from the ***Mississippi River***, and three from the ***Meramec River***. The remaining 36 are from other streams (table 4). Individual water supply reservoirs and surface-water intakes will be discussed in more detail in later sections of this report.

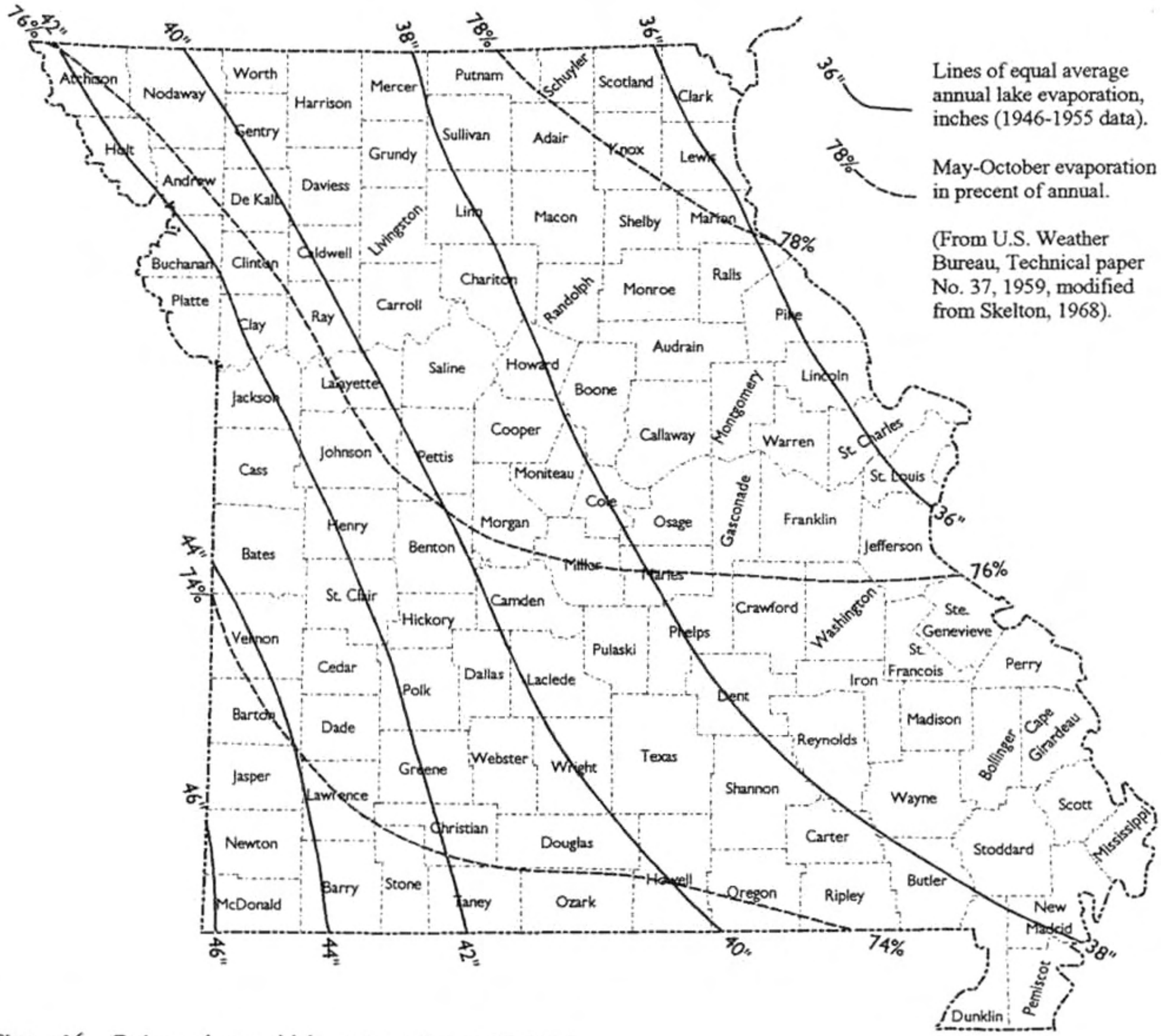

Figure 16. Estimated annual lake evaporation in Missouri.

NAME OF SUPPLY	NAME OF STREAM	COUNTY
MISSOURI RIVER		
St. Joseph	Missouri River	Buchanan
Kansas City	Missouri River	Clay
Lexington	Missouri River	Lafayette
Higginsville	Missouri River	Lafayette
Glasgow	Missouri River	Howard
Boonville	Missouri River	Cooper
Jefferson City	Missouri River	Cole
St. Louis (Howard Bend)	Missouri River	St. Louis
St. Louis (Central Plant)	Missouri River	St. Louis
St. Charles	Missouri River	St. Charles
St. Louis (North Plant)	Missouri River	St. Louis
MISSISSIPPI RIVER		
Canton	Mississippi River	Lewis
Hannibal	Mississippi River	Marion
Louisiana	Mississippi River	Pike
St. Louis (Chain of Rocks)	Mississippi River	St. Louis
Cape Girardeau	Mississippi River	Cape Girardeau
MERAMEC RIVER		
Kirkwood	Meramec River	St. Louis
St. Louis County (South Plant)	Meramec River	St. Louis
St. Louis County (Meramec Plant)	Meramec River	St. Louis
OTHERS		
Adrian	South Grand River	Bates
Amoret	Marais De Cygnes River	Bates
Archie	South Grand River	Cass
Bates Co. PWSD #2	Miami Creek	Bates
Branson	Lake Taneycomo	Taney
Brookfield	Yellow Creek	Linn
Bucklin	Mussel Fork Creek	Macon
Butler	Marais De Cygnes River	Bates
Butler	Miami Creek	Bates
Cass Co. PWSD #7	South Grand River	Cass
Chillicothe	Grand River	Livingston
Clinton	South Grand River	Henry
Dearborn	Bee Creek	Platte
Fredericktown	Little St. Francis River	Madison
Gower	Castile Creek	Clinton
Jefferson Co. PWSD #2	Big River	Jefferson
Joplin	Shoal Creek	Newton
Marceline	Mussel Fork Creek	Linn
Maryville	One Hundred and Two River	Nodaway
Neosho	Shoal Creek	Newton
New London	Salt River	Ralls
Paris	Middle Fork Salt River	Monroe
Perryville	Saline River	Perry
Piedmont	Black River	Wayne
Plattsburg	Smithville Reservoir	Clinton
Poplar Bluff	Black River	Butler
Ralls Co. PWSD #1	Salt River	Ralls
Ridgeway	Big Creek	Harrison
Rockville	Osage River	Bates
Sedalia	Flat River	Pettis
Shelbina	Salt River	Shelby
Smithville	Little Platte River	Clay
Springfield	James River	Greene
Sweet Springs	Blackwater River	Saline
Trenton	Thompson River	Grundy
Wyaconda	Wyaconda River	Clark

Table 4. Public water supply intakes on rivers and streams (DEQ, 1991)

SURFACE WATER QUALITY

Water falling through the atmosphere as precipitation contains very little dissolved or suspended materials. Upon striking the ground, water begins to dissolve soluble materials that affect the quality and potential uses of the water. In addition, clays and other sediments can also be carried with moving water as suspended material. The amount of suspended matter in surface water can also affect its potential uses and the cost of treatment.

Most of the dissolved constituents found in surface water are from soluble earth materials. Ions such as calcium, magnesium, silica, iron, manganese, bicarbonate, sulfate, chloride, potassium, and sodium are all common dissolved constituents to be found in surface water. For drinking water, the sulfate and chloride contents should each be below 250 milligrams per liter (mg/l). Total dissolved solids should be less than 500 mg/l, although depending on the concentrations of specific ions, total dissolved solids as high as 1,000 mg/l can be tolerated for certain uses. Iron and manganese are present in most water, but iron levels above 0.3 mg/l, and manganese content greater than 0.05 mg/l, can give the water a metallic taste and stain laundry and plumbing fixtures.

Nutrients such as nitrate, nitrite, ammonia, and phosphate are present in varying amounts in surface water. All of these are common constituents in commercial fertilizers, and most are also found in animal and human wastes.

Most of the surface water in Missouri is of good chemical quality, and most constituents are within recommended levels. Sulfate and chloride are generally well under 250 mg/l each, and total dissolved solids are usually less than 500 mg/l. Nitrogen and phosphorous levels vary greatly, depending on agricultural runoff or the presence of wastewater discharges in the watershed. For drinking water, nitrate content should be less than 10 mg/l (as nitrogen). Pesticides may be present in surface water in agricultural areas, but are generally in very low quantities. However, recent sampling has found concentrations of certain pesticides that are above maximum contaminant levels in some surface water sources in northern and western Missouri (Cunningham, 1995; personal communication).

Soils in many areas of Missouri are easily eroded. In northern and western Missouri, where row-cropping is most common, rivers and streams often have high suspended sediment loads, particularly after heavy rainfall. Suspended sediment is normally low in Ozark streams except during periods of high runoff. In recent years, changes in farming practices and erosion reduction programs have decreased the amount of soil erosion in Missouri, and reduced the suspended sediment loads of many streams.

Surface water and groundwater quality will be discussed more fully in future **State Water Plan** documents.

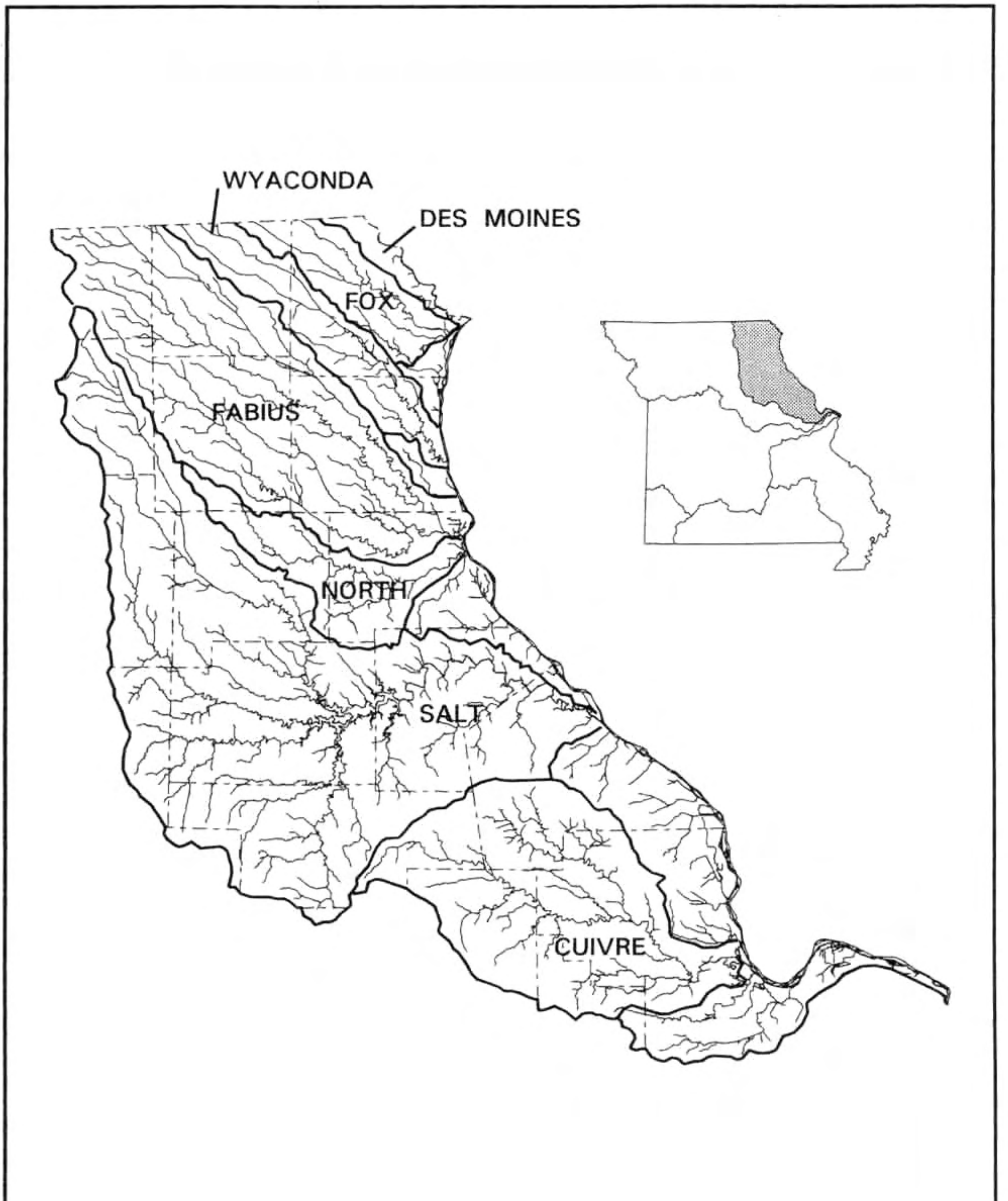

Figure 17. Upper Mississippi River tributaries in Missouri.

MISSOURI SURFACE WATER RESOURCES: BASIN DESCRIPTIONS

The following sections describe the surface water resources of smaller river basins within the state's major river watersheds. Flow characteristics, basin size, reservoir development, runoff volumes and rates, and other factors are given for selected rivers. River basins are presented in the following order: Upper Mississippi River tributaries, Missouri River tributaries north of the Missouri River, Missouri River tributaries south of the Missouri River, Lower Mississippi River tributaries, White River tributaries, and Arkansas River tributaries.

Nearly all discharge information for streams has been taken from U.S. Geological Survey water resources data reports for various water years. Most average values are based on water years rather than calendar years. A water year is the 12-month period beginning the preceding October 1 and ending September 30. In other words, water year 1993 covers the year beginning October 1, 1992, and ending September 30, 1993.

Most information on drainage basin sizes has been taken from *Mineral and Water Resources of Missouri* (MGS, 1967). Public water supply intake and reservoir data, as well as other public water supply information was provided by the Public Drinking Water Program through their 1991 *Census of Missouri Public Water Systems*, (the most recent published census). Where possible, more recent surface-water supply information was obtained directly from DNR regional office personnel in Macon (Everett Baker) and Kansas City (William Hills). The *Missouri Water Atlas* (Atlas, 1986) was also used extensively as a source of information.

UPPER MISSISSIPPI RIVER TRIBUTARIES

Many authorities consider the boundary between the ***upper*** and ***lower Mississippi River*** basin to be the ***Ohio River***. However, for purposes of this report, the term "upper Mississippi River" will refer to that reach of the Mississippi upstream from the confluence of the Missouri and Mississippi rivers, and the "lower Mississippi River" will include the reach downstream from the confluence of the Missouri and Mississippi rivers.

The ***upper Mississippi River*** drains approximately 171,300 square miles, of which about 7,790 square miles is in Missouri and accounts for about 11.2 percent of the state. Average annual runoff from this area in Missouri ranges from about 7 inches in the northwest corner to about 10 inches in the southeast near St. Louis. The drainage patterns of the northern tributaries in this area are quite similar. Basins are southeast trending, and are generally relatively long with respect to their width. Several of the basins have their headwaters in southeastern Iowa. Figure 17 shows the drainage area of the upper Mississippi River basin in Missouri, and gives the names and locations of major tributary streams.

Most of northeast Missouri is covered by a thick mantle of glacial drift ranging from zero to more than 300 feet thick, and averaging about 100 feet thick. The glacial materials in this region are generally thickest in the upland areas in Schuyler County, and thinnest or absent along the lower reaches of the major streams in the central and southeastern part of the area. Loess, which is wind-blown silt derived from the floodplains of major rivers and deposited on the uplands during the Pleistocene (Ice Age), covers part of the ***Mississippi River basin*** in Missouri. The loess is generally thickest along the bluffs adjacent to the Mississippi River, thinning to the west. Repetitive limestone, sandstone, and shale formations of Pennsylvanian-age underlie the drift in the western part of the basin; Mississippian-age limestones and shales and older sedimentary rock underlie the drift in the eastern part of the basin, particularly along the Lincoln fold. The Lincoln Fold is a northwest-trending anticline that parallels the Mississippi River through Lincoln, Pike, Ralls, and Marion counties.

The flow characteristics of most of the rivers in this area show similar patterns. Groundwater inflow into the streams is typically low, even during wet weather. During extended droughts, most of the rivers have periods of no flow.

The chemical quality of water in streams in this area is generally good. The water is normally a calcium-magnesium-bicarbonate type. Total dissolved solids are generally less than 500 milligrams per liter (mg/l). Sulfate is present in moderate levels in many of the rivers, but is generally less than 150 mg/l. Nitrate, ammonia, and phosphate levels are ordinarily below 1 mg/l, but elevated levels can occur due to agricultural wastes, chemical fertilizers, and wastewater discharges. Bacteria levels are variable, depending on season and wastewater inflows. Suspended sediment content is often high, and increases greatly after heavy precipitation (Gann and others, 1971).

Most of the towns in the basin, especially in the northern part, depend on surface water for public water supply and have reservoirs. Several either use an intake in a river, or supplement reservoir storage with water from a stream. Groundwater resources in most of northeastern Missouri are poor. The glacial drift typically does not contain appreciable clean sand, and supplies only modest quantities of water of marginal quality. Several towns in the southern part of the region, south of the fresh water-saline water transition zone, use deep wells that produce from bedrock aquifers. Rural residents not using water from public water supply districts typically use shallow wells or cisterns for domestic needs. Public water from rural water districts is available in part of the area. Glacial drift in the area is typically suitable for developing ponds, which are widely used for stock watering and, to a much lesser extent, for private surface water supply.

Des Moines River

The ***Des Moines River***, which drains much of southeastern Iowa, has a total drainage area of about 15,000 square miles. However, only about 80 square miles of the drainage basin lies in Missouri. The Des Moines River forms the northern boundary of the state for about a 20 mile reach in Clark County. Because of row-crop farming, the river carries a high sediment load and typically has a relatively high nitrate level.

Fox River

The ***Fox River*** rises in southeast Iowa, and enters the ***Mississippi River*** about six miles below the mouth of the ***Des Moines River*** in Clark County. The basin contains about 502 square miles with about 278 square miles in Missouri. The Fox drains much of Clark County and the northeast corner of Scotland County. Like many of the northern Missouri streams, the basin is relatively long and narrow. It is about 75 miles long, but at the most only about 10 miles wide.

Upstream from *Wayland*, the ***Fox River*** drains about 400 square miles. From 1933 through 1993, discharge has averaged 262 ft^3/sec (about 8.9 in/yr). Average yearly runoff at this point is about 189,900 ac-ft. The highest average annual flow, 927 ft^3/sec, occurred in water year 1993. The water year with the lowest average annual flow was 1956 when it averaged only 17.6 ft^3/sec. Peak recorded flow was April 22, 1973, at 26,400 ft^3/sec.

Figure 18 is a flow-duration curve for the ***Fox River*** at *Wayland*. Historically, flow of the river at Wayland is less than 2.0 ft^3/sec 10 percent of the time. Fifty percent of the time

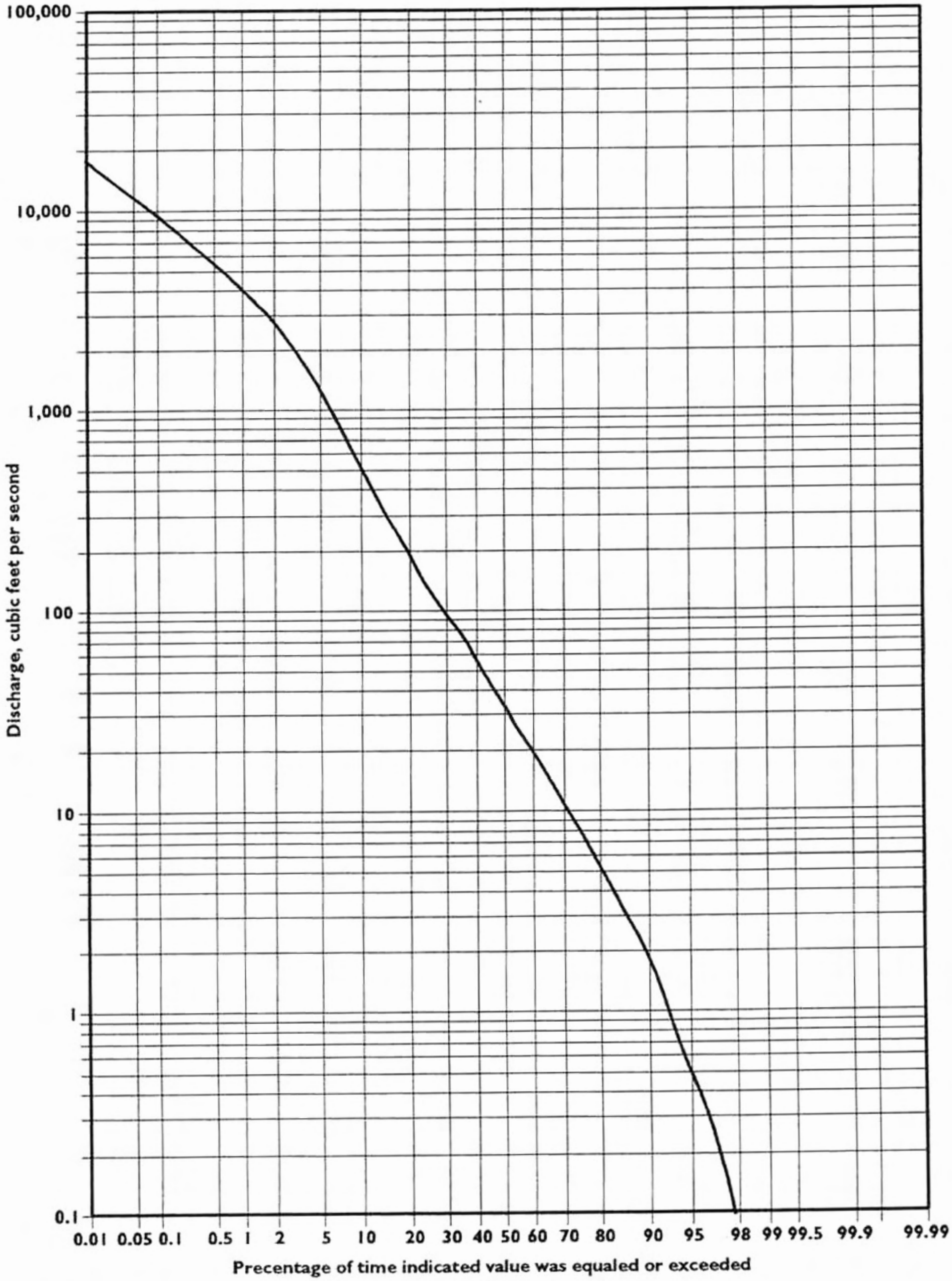

Figure 18. Flow-duration curve, Fox River at Wayland, 1923-1993.

the flow is less than 37 ft^3/sec. Zero flow conditions have been observed during several years. Based on 1922-1959 flow data, Skelton (1966) determined the 7-day Q_2 for the Fox River at Wayland to be 1.1 ft^3/sec. The 7-day Q_{10} was calculated to be zero. The 7-day Q_2 for a stream is the 7 day low-flow discharge that has a recurrence interval of two years. More specifically, the 7-day Q_2 for a stream is the average minimum flow for 7 consecutive days that has a recurrence interval of 2 years. In any year, there is a 50 percent chance that the average minimum discharge for 7 consecutive days will be less than the 7-day Q_2 value. The 7-day Q_2 values are useful for evaluating the ability of a stream to provide a given volume of water during drought periods.

Wyaconda River

The ***Wyaconda River*** consists of northern and southern tributaries, both of which rise in southeastern Iowa. The basin drains about 458 square miles, of which about 336 square miles lies in Missouri. Its watershed is extremely narrow, generally ranging in width from 5 to 8 miles throughout its 70 mile length. It drains parts of Scotland, Clark, and Lewis counties. Near *Canton*, where it drains 393 square miles, it has an average annual runoff of 8.9 inches and an average annual discharge of 259 ft^3/sec. Flow is less than 1.9 ft^3/sec 10 percent of the time, and less than 30 ft^3/sec 50 percent of the time. The water-year of lowest runoff, based on records from 1932 to 1993, was 1989 when it averaged 14.2 ft^3/sec. Water year 1993 was the highest-flow year on record when discharge averaged 861 ft^3/sec.

The City of *Wyaconda* has a water-supply reservoir in this watershed. The reservoir is on a tributary of the ***Wyaconda River***, and has a surface area of about 8 acres (DEQ, 1991). Reservoir storage is supplemented by pumping from the ***South Wyaconda River***.

Fabius River

The ***Fabius River*** has its headwaters in extreme southeastern Iowa, and consists of major north, middle, and south tributaries. The ***North Fabius*** is joined by its main tributary, the ***Middle Fabius***, upstream of *Taylor*. The ***South Fabius*** joins the combined North and Middle Fabius several miles downstream of Taylor. The total drainage area is about 1,570 square miles; Missouri contains 1,470 square miles of the watershed. The basin is about 80 miles long, and as much as 25 miles wide. Most of Schuyler and Knox counties, and parts of Scotland, Lewis, Adair, and Marion counties drain into the Fabius.

There are 13 reservoirs in the basin that provide public water supplies:

♦*Lancaster* has two reservoirs that furnish municipal water. The old reservoir has a surface area of about 10 acres, and the new reservoir about 41 acres.

♦*Downing* uses an 18-acre lake for municipal water supply.

♦*Memphis* uses three reservoirs having 2.06 acres, 42.6 acres, and 247.6 acres of surface areas.

♦*Edina* uses two lakes having 14 acres and 42 acres of surface area.

♦*Lewistown* uses a 31-acre lake, and Lewis County PWSD #1 has a 60-acre reservoir.

♦*Baring* uses an 81-acre reservoir at a local country club.

♦*LaBelle* uses two reservoirs having 17 acres and 162 acres of surface area.

There are no gaging stations on the main stem of the ***Fabius River*** below the confluence of its various forks. At *Monticello*, the ***North Fabius*** drains about 452 square miles. From 1922 through 1993, the stream here averaged 8.82 inches of runoff. Average annual discharge was 294 ft^3/sec. The years of highest and lowest average flows were 1993 when flow averaged 923 ft^3/sec, and 1989 when average flow for the year was 18.0 ft^3/sec. Peak discharge at this station was 20,700 ft^3/sec on April 22, 1973; minimum flow is zero, which has occurred many times throughout the period of record. Discharge of the stream is less than 4 ft^3/sec about 10 percent of the time, and less than 45 ft^3/sec about 50 percent of the time. The 7-day Q_2 for the North Fabius at Monticello is 2.1 ft^3/sec (Skelton, 1966).

The ***Middle Fabius River*** near *Monticello* drains 393 square miles, and from 1945 through 1993 its average runoff was 9.52 inches. Average flow for the period of record is 275 ft^3/sec. Water years of highest and lowest average annual flows were 1993, when flow averaged 837 ft^3/sec, and 1989, when it averaged 18.7 ft^3/sec. The highest instantaneous discharge ever recorded at the station occurred April 23, 1973, when it was 15,100 ft^3/sec. Periods of no flow have been observed many times during dry weather, and the 7-day $Q_2$is 0.8 ft^3 (Skelton, 1966).

The ***South Fabius River*** near *Taylor* drains 620 square miles and, based on discharge data collected from 1934 through 1993, has a average annual runoff of 8.94 inches. Average discharge throughout the period of record is 408 ft^3/sec. Figure 19 shows average daily discharge for the stream during years of lowest and highest recorded flows. In 1989, average discharge for the year was only 27.4 ft^3/sec. In 1993, average discharge was 1,147 ft^3/sec. Peak recorded flow was on June 8, 1947, at 19,700 ft^3/sec, and there have been several instances of no flow. Figure 20 is a flow-duration curve for the ***Fabius River*** near Taylor. About 10 percent of the time, flow is less than 4 ft^3/sec, and 50 percent of the time flow is less than 59 ft^3/sec. Skelton (1966) shows a 7-day Q_2 of 1.2 ft^3/sec for the stream.

North River

The ***North River*** drains a 382 mi^2 area immediately south of the ***Fabius River*** basin. Most of the drainage is in Shelby and Marion counties, but also includes a small part of Knox County. The basin is about 55 miles long, a maximum of 14 miles wide, and enters the

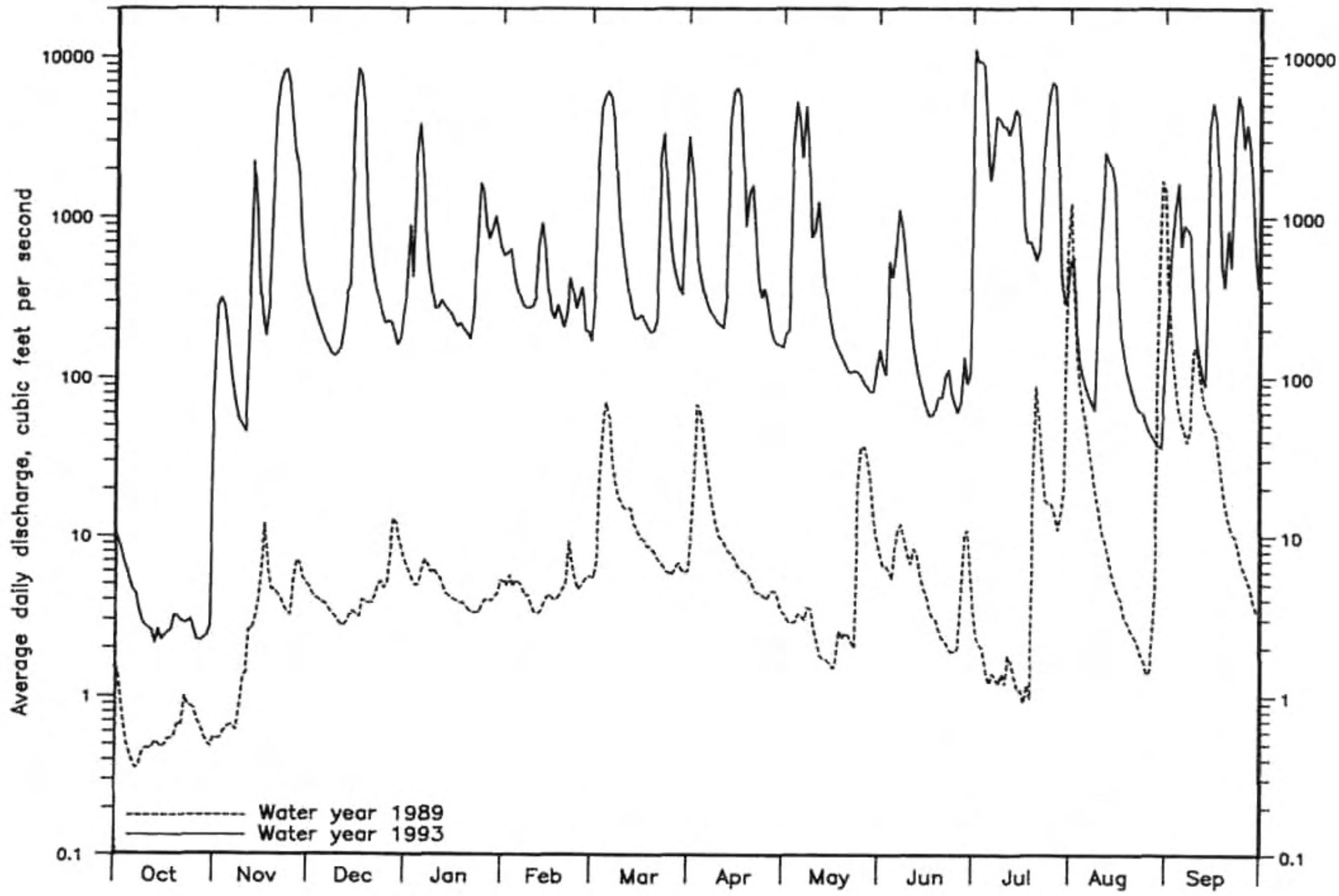

Figure 19. South Fabius River near Taylor, water years 1989 and 1993.

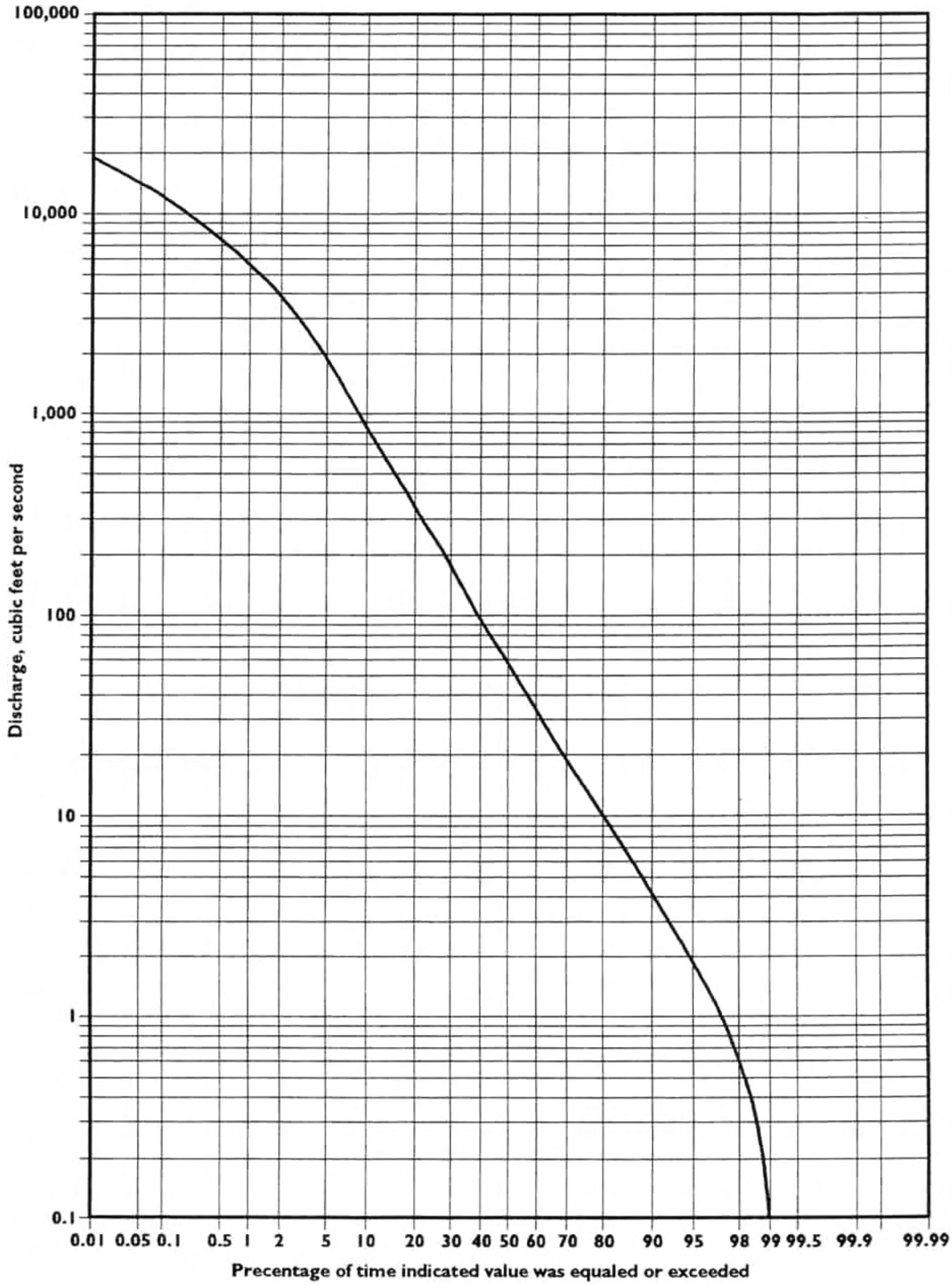

Figure 20. Flow-duration curve, South Fabius River near Taylor, water years 1936-1993.

Mississippi River some 3 miles downstream of the mouth of the Fabius River. At *Palmyra*, about 7 miles upstream from the mouth, the river drains 373 square miles and has an average runoff rate of 9.61 inches, based on data collected between 1934 and 1993. Average discharge throughout this period was 264 ft^3/sec. The water year of highest flow was 1973 when it averaged 748 ft^3/sec. Lowest average annual flow occurred in water year 1989 when it was 22.1 ft^3/sec. There have been numerous periods of no flow.

Like all northeast Missouri streams, the ***North River*** has a poorly-sustained base flow during dry weather. About 10 percent of the time, flow is less than 3.2 ft^3/sec. Flows of less than 39 ft^3/sec occur 50 percent of the time.

Salt River

The ***Salt River*** basin is the largest ***Mississippi River*** tributary north of the ***Missouri River*** in Missouri. In northern Missouri it is exceeded in drainage area only by the ***Grand River*** basin. The Salt drains 2,920 square miles, all in Missouri. Its headwaters are in Schuyler County, and it drains all or parts of Adair, Knox, Callaway, Macon, Pike, Shelby, Randolph, Boone, Monroe, Ralls, and Audrain counties. The river flows into the ***Mississippi River*** near *Louisiana*. The basin is about 125 miles long, and up to 40 miles wide. The Salt consists of three major forks, largest of which is the southernmost. The ***South Fork Salt River*** drains 1,220 square miles. Clarence Cannon Dam, the U.S. Army Corps of Engineers Reservoir which forms ***Mark Twain Lake***, impounds water in Ralls and Monroe counties, and regulates flow of the lower Salt River.

There are numerous gaging stations within the ***Salt River*** basin. The ***North Fork Salt River*** near *Shelbina* drains 481 square miles and has an average annual runoff of 8.19 inches, based on 47 years of record between 1930 and 1993. Average discharge throughout the period of record is 290 ft^3/sec. Water years of lowest and highest flows were 1989 and 1993, respectively, when average yearly flows were 36.2 ft^3/sec and 1,037 ft^3/sec. Peak recorded flow occurred June 7, 1947, at 23,000 ft^3/sec; periods of zero flow occur during extremely dry weather. Discharges of less than 1.5 ft^3/sec occur about 10 percent of the time, and flow is less than 30 ft^3/sec 50 percent of the time.

The ***Middle Fork Salt River***, measured at *Paris*, has a higher runoff rate of 9.79 inches. The river here drains 356 square miles, and has an average flow of 257 ft^3/sec. In water year 1973, the year of highest average flow, discharge averaged 743 ft^3/sec. Lowest average annual flow was during water year 1956 when it averaged 53.1 ft^3/sec. The highest flow ever recorded at Paris was April 21, 1973, when discharge peaked at 45,000 ft^3/sec; zero flow occurs during extended dry weather. Discharge of the river here is less 30 ft^3/sec about 50 percent of the time, and less than 1.8 ft^3/sec 10 percent of the time.

The ***South Fork Salt River*** above *Sante Fe* drains about 233 square miles, and between 1940 and 1993 it had an average annual runoff of 11.31 inches. Average flow of the stream here is 194 ft^3/sec, with highest and lowest average annual discharges occurring in water years 1969 and 1954, respectively, at 509 ft^3/sec and 10.7 ft^3/sec. Peak discharge here occurred September 23, 1993, at 31,800 ft^3/sec. Flow is less than 1.4 ft^3/sec 10 percent of the time, and less than 16 ft^3/sec 50 percent of the time.

Figure 21 is a flow-duration curve for the ***Salt River*** at *New London*, based on data collected between water years 1923 and 1993. The curve shows low base flow conditions. However, much of the data were collected prior to construction of Clarence Cannon Dam. Today, releases from ***Mark Twain Lake*** help to sustain higher base-flows in the Salt River downstream from the dam. Only about 5 percent of the 2,480 square miles of drainage upstream from New London is not regulated by Clarence Cannon Dam. Average annual flow here is 1,721 ft^3/sec (about 9.43 inches). Water years of highest and lowest average annual flows were 1973 and 1989, respectively, at 4,692 ft^3/sec and 307 ft^3/sec. Peak recorded flow at this station is 107,000 ft^3/sec,

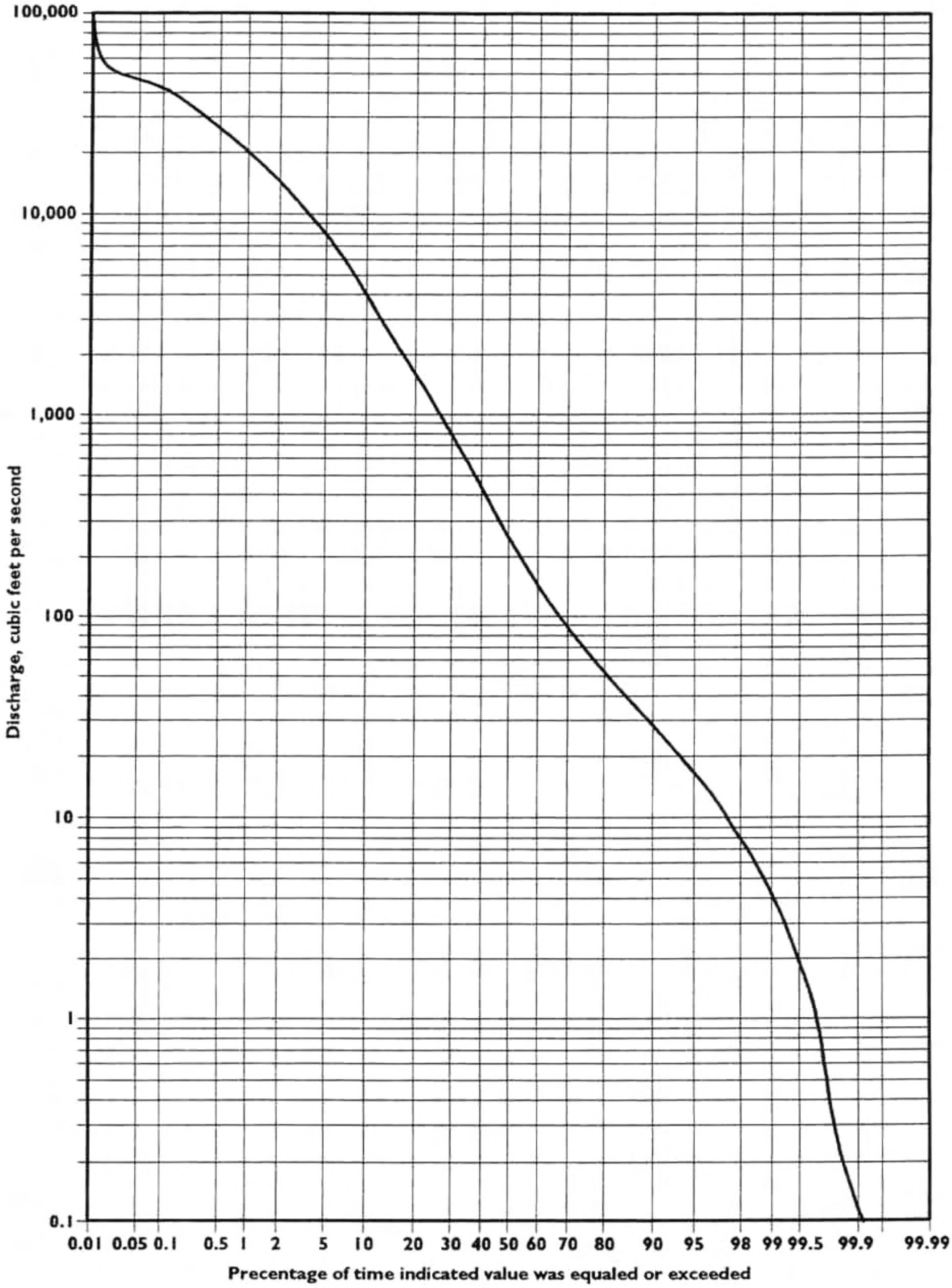

Figure 21. Flow-duration curve, Salt River near New London, water years 1923-1993.

which occurred on April 22, 1973. Periods of no flow occurred during an extended drought in 1934 and 1936.

Mark Twain Lake, impounded by Clarence Cannon Dam, is the only major reservoir in northeastern Missouri in the ***Mississippi River*** basin. Construction of Clarence Cannon Dam which forms the lake was finished in 1984. Upstream from the dam the reservoir drains 2,318 square miles. Clarence Cannon Dam is 1940 ft long and 138 ft high. At multipurpose pool level (elevation 606 ft), the surface area of Mark Twain Lake is 18,600 acres, and storage is 457,000 ac-ft. Flood control pool level is 638 ft, the surface area at this elevation is 38,400 acres, and storage is 1,428,000 ac-ft.

Mark Twain Lake is used for flood control, recreation, and water supply. It is capable of supplying about 16 million gallons of water per day (mgd) from its 20,000 ac-ft of water-supply storage with a 2 percent chance of deficiency. The Clarence Cannon Wholesale Water Commission (CCWWC) currently distributes water from the reservoir to a large area around the reservoir. Besides supplying water to residents in the ***Salt River*** basin, water from ***Mark Twain Lake*** is being used by residents in adjoining watersheds.

Besides ***Mark Twain Lake,*** there are about 12 other municipal water supply reservoirs in the ***Salt River*** basin, although some of these are not currently in use:

♦Schuyler County PWSD #1 uses a 29-acre lake near *Queen City* in the upper part of the ***North Fork Salt River*** watershed.

♦*La Plata* has two reservoirs containing 26 and 81 acres of surface area.

♦*Clarence* has two reservoirs with 18 acres and 31 acres of surface area.

♦*Shelbyville* formerly used a 29-acre reservoir, but now uses water from ***Mark Twain Lake*** (CCWWC). Nearby *Shelbina* has a 45-acre reservoir but also pumps from the ***North Fork Salt River*** into the reservoir.

♦*Monroe City* has three reservoirs with surface areas of 20 acres, 43 acres, and 131 acres.

♦*Perry* is supplied from ***Mark Twain Lake*** by the CCWWC, but previously used 2 reservoirs with 7.4 and 15 acres of surface areas.

♦Ralls County PWSD #1 formerly used a pump-storage reservoir with water pumped from the river, but is now supplied from Hannibal.

♦*Paris* and *New London* formerly used surface water directly from intakes in the ***Middle Fork Salt River*** and ***Salt River***, respectively. Now both obtain water from the CCWWC.

In addition to the above, ***Mark Twain Lake*** through the CCWWC also supplies part or all of the water used by Shelby County PWSD #1, Knox County PSWD #1, Monroe County PWSD #2, Marion County PWSD #1, and Cannon PWSD #1. To the west in the Chariton River basin Mark Twain Lake water is supplied to Huntsville and Thomas Hill PWSD #1. Higbee, in Bonne Femme Creek basin also uses water from Mark Twain Lake.

Cuivre River

The ***Cuivre River*** is the southernmost major river basin on the upper ***Mississippi River*** in northeast Missouri. It is about 60 miles long and 40 miles wide, and drains 1,230 square miles in Audrain, Pike, Lincoln, Montgomery, Warren, and St. Charles counties. Pennsylvanian-age strata forms the bedrock surface throughout the central and western watershed; Mississippian-age and older formations underlie the lower part of the basin. Glacial Drift is thickest in the upper watershed and thins to the east.

The ***Cuivre River*** near *Troy*, which drains about 903 mi^2, has an average discharge of 666 ft^3/sec and an annual runoff rate of 10.01 inches. Highest and lowest average annual discharges occurred in water years 1993 and 1954, respectively. Average discharge for water year 1993 was 2,186 ft^3/sec, and for water year 1954 it was 27.4 ft^3/sec. Peak recorded flow for the river near Troy is 120,000 ft^3/sec, which occurred October 5, 1941. Periods of no discharge have occurred several times. Figure 22 is a flow-duration curve for the ***Cuivre River*** near *Troy*. It shows flow-duration characteristics quite similar to other rivers in northeast Missouri. Based on 64 years

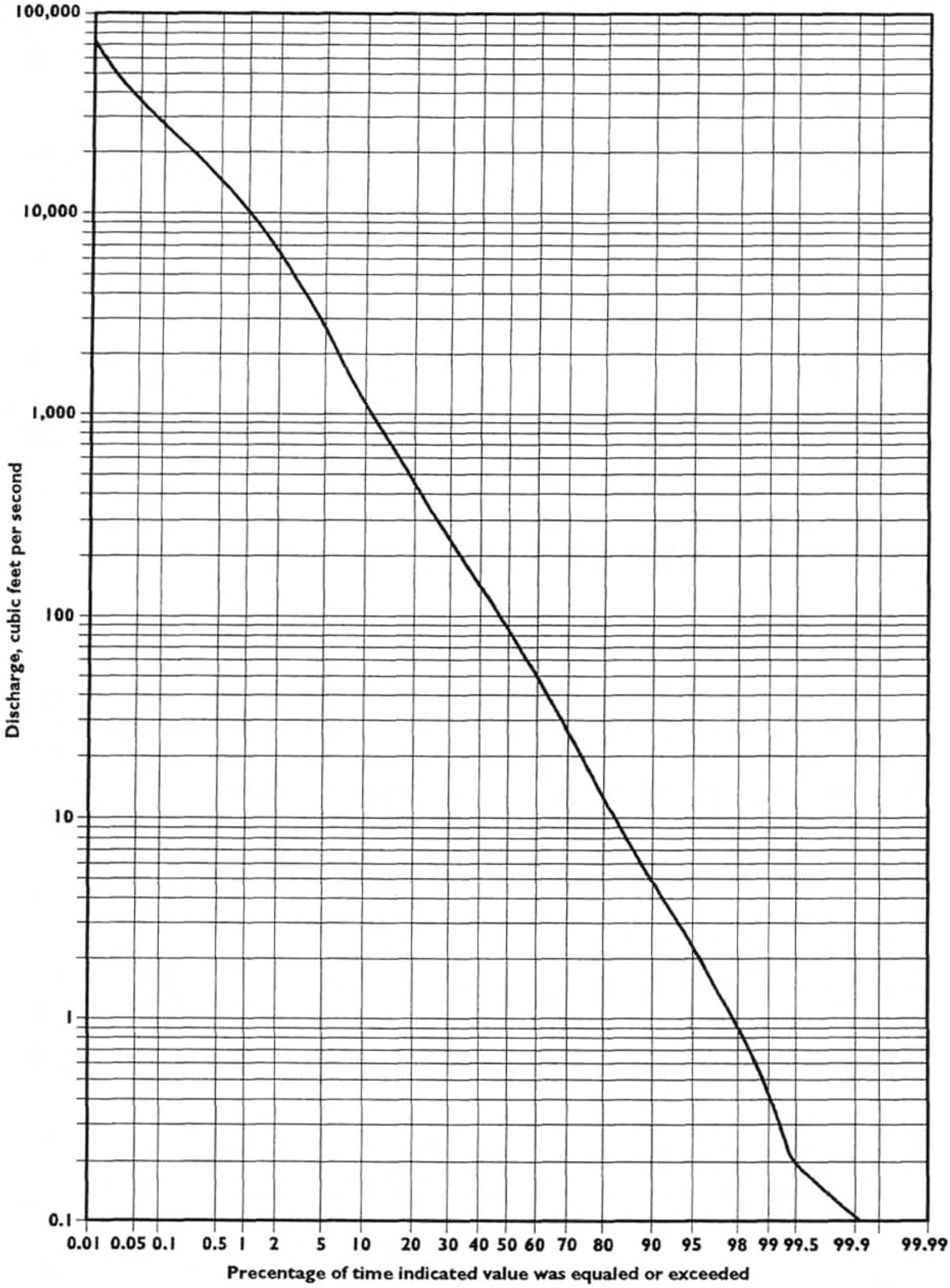

Figure 22. Flow-duration curve, Cuivre River near Troy, water years 1923-1993.

of records between 1922 and 1993, flow is less than 5.4 ft^3/sec 10 percent of the time, and less than 88 ft^3/sec 50 percent of the time.

The City of *Vandalia* in Audrain County uses a 37-acre reservoir in the upper part of ***Cuivre River*** watershed for water supply.

Other Upper Mississippi River Tributaries

The upper ***Mississippi River*** tributaries discussed previously drain about 6,700 square miles. The remaining 1,090 square miles of this area of northeast Missouri is drained by a number of smaller watersheds. In downstream order, these include the ***South River***, ***Bear Creek***, ***Noix Creek***, ***Buffalo Creek***, ***Ramsey Creek***, ***Guinns Creek***, ***Bryants Creek***, ***Bobs Creek***, ***Peruque Creek***, and ***Dardenne Creek***. Very little discharge information is available for these smaller streams and their watersheds. ***Bear Creek***, which is near *Hannibal*, is an exception. Upstream from the gaging station, which is 4.65 miles from its mouth, ***Bear Creek*** drains about 31 square miles. Average discharge for 51 years of records is 21.1 ft^3/sec (about 9.24 in./yr of runoff). A flood control reservoir about 1 mile upstream from the gaging station regulates high flows.

The City of *Bowling Green* in Pike County uses two reservoirs in the upper watershed of ***Noix Creek*** for water supply. The newest reservoir has a surface area of 45 acres, and the older has a surface area of 20 acres.

Main Stem Mississippi River

Flow of the ***Mississippi River*** upstream from *St. Louis* is partly regulated by a series of 27 locks and dams that are used to maintain a navigation channel in the river. The uppermost lock and dam that directly affects the state of Missouri is lock and dam no. 19 at *Keokuk*, Iowa. The downstream-most dam on the Mississippi, no. 27, is a few miles below the confluence of the ***Missouri*** and Mississippi rivers. Its navigation lock, however, is a few miles southeast of the dam near the mouth of the Chain of Rocks Canal at *Granite City*, Illinois. Between Keokuk and St. Louis are locks and dams at *Canton*, *West Quincy*, *Saverton*, *Clarksville*, *Winfield*, and *West Alton*.

The USGS gaging station at *Grafton*, Illinois, is the only gaging station on the ***upper Mississippi River*** in Missouri. However, another gaging station is located at *Keokuk*, Iowa, just 2.7 miles upstream from the mouth of the ***Des Moines River***.

Discharge of the ***Mississippi River*** has been measured at *Keokuk* since 1878. Upstream from here, the river drains an area of about 119,000 square miles. Average discharge at Keokuk is 65,380 ft^3/sec, and average annual runoff is 7.46 inches. Water year 1993 had the highest average annual flow of 162,500 ft^3/sec. Peak discharge for the station also occurred in 1993. On July 10, discharge peaked at 446,000 ft^3/sec. In water year 1934, the year of lowest average flow, discharge averaged 21,540 ft^3/sec. The lowest daily flow ever measured here was 5,000 ft^3/sec, which was recorded December 27, 1933. Discharge of the Mississippi River at Keokuk exceeds 23,000 ft^3/sec 90 percent of the time, and is more than 49,600 ft^3/sec 50 percent of the time

Upstream from *Grafton*, Illinois, just downstream of the confluence of the ***Illinois*** and ***Mississippi*** rivers, the Mississippi drains about 171,000 mi^2, but only about 4.6 percent of this area lies in Missouri. Drainage from Missouri provides about 5 percent of the flow of the Mississippi River here.

Between 1879 and 1892, and from 1929 through 1993, the ***Mississippi River*** at *Grafton* had an average discharge of 122,800 ft^3/sec. Water year 1993 had the highest annual flow with an average discharge of 250,800 ft^3/sec, and the highest peak flow ever recorded at the station. On August 1, 1993, discharge peaked at 598,000 ft^3/sec. Lowest recorded flow was on December 14, 1988, at 20,100 ft^3/sec. Water year 1989 was the lowest year of flow for the Mississippi River here when it averaged 53,600 ft^3/sec. Average annual runoff for the basin is 9.74 inches. Figure 23 is a flow-duration curve for the Mississippi River at Grafton based on 106 years of record between 1887 and 1993. During this period, flow exceeded 36,400 ft^3/sec about 90 percent of the time, and 92,400 ft^3/sec about 50 percent of the time. Flows of more than 250,000 ft^3/sec occurred 10 percent of the time.

Between *Keokuk* and *Grafton*, the average flow of the ***Mississippi River*** increases about 57,420 ft^3/sec (about 88 percent). Average annual runoff increases 2.28 inches (about 31 percent). The drainage area increases about 52,300 square miles, or about 44 percent. Only about 15 percent of the increase in drainage area is from Missouri. Most of the remaining drainage area increase is from the ***Des Moines River*** basin, which drains much of central and southeastern Iowa, and the ***Illinois River***, which drains much of northern Illinois.

Three cities in northeastern Missouri rely on the upper ***Mississippi River*** for water supply. *Canton, Hannibal,* and *Louisiana* all have water-supply intakes that produce from the river.

MISSOURI RIVER TRIBUTARIES NORTH OF THE MISSOURI RIVER

The ***Missouri River*** drains approximately 52.4 percent of the state, an area of about 36,537 square miles. About 44 percent of this, an area of about 16,245 square miles, lies north of the river (figure 24).

Like the ***upper Mississippi River*** basin in northeastern Missouri, north-central and northwestern Missouri have been glaciated. Glacial materials in this area are also unconsolidated deposits of clay, silt, sand, and gravel that may be as much as 300 feet thick, but average about 100 feet. The shallow glacial till has a low permeability, and does not contribute appreciable amounts of groundwater to area streams. Preglacial valleys that were filled with glacial drift are more water-productive. These valleys are typically well below the level of the present drainage and do not provide measurable inflow to streams, but wells producing from them are used to meet some of the water supply needs of a few towns in the area. The glacial drift is underlain by Pennsylvanian-age bedrock throughout much of the area except in the south-central and southeastern regions where Mississippian-age and older rock formations form the bedrock surface.

The quality of surface water in north-central and northwestern Missouri is generally good. Like in northeastern Missouri, the water is generally a moderately mineralized calcium-magnesium-bicarbonate type, and total dissolved solids are typically below 500 mg/l. Sulfate and

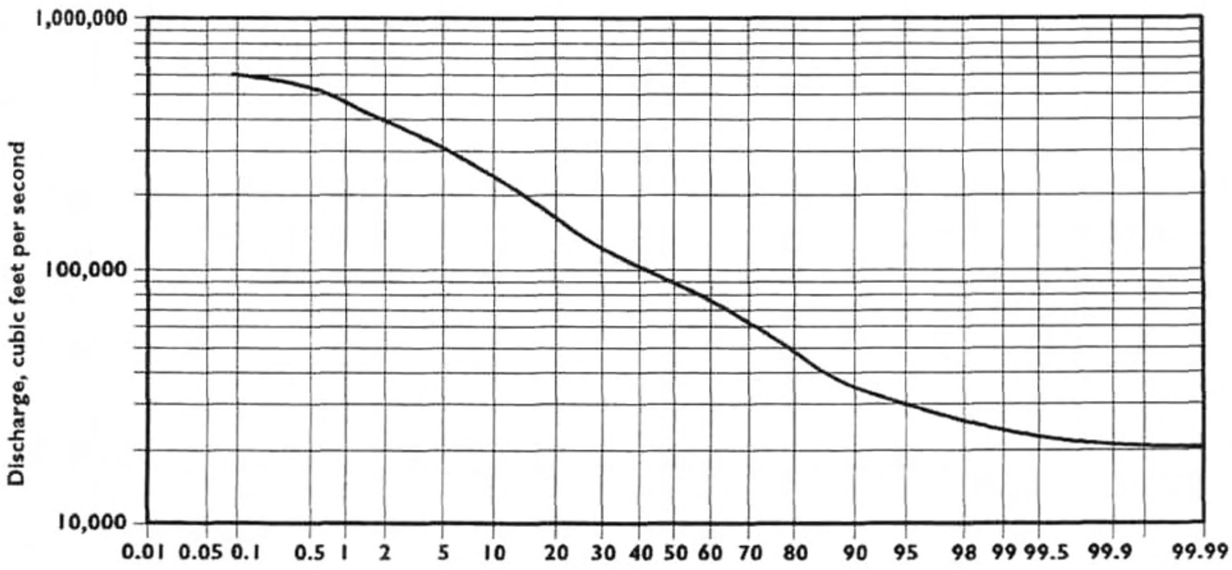

Figure 23. Flow-duration curve, Mississippi River at Grafton, Illinois, water years 1987-1993.

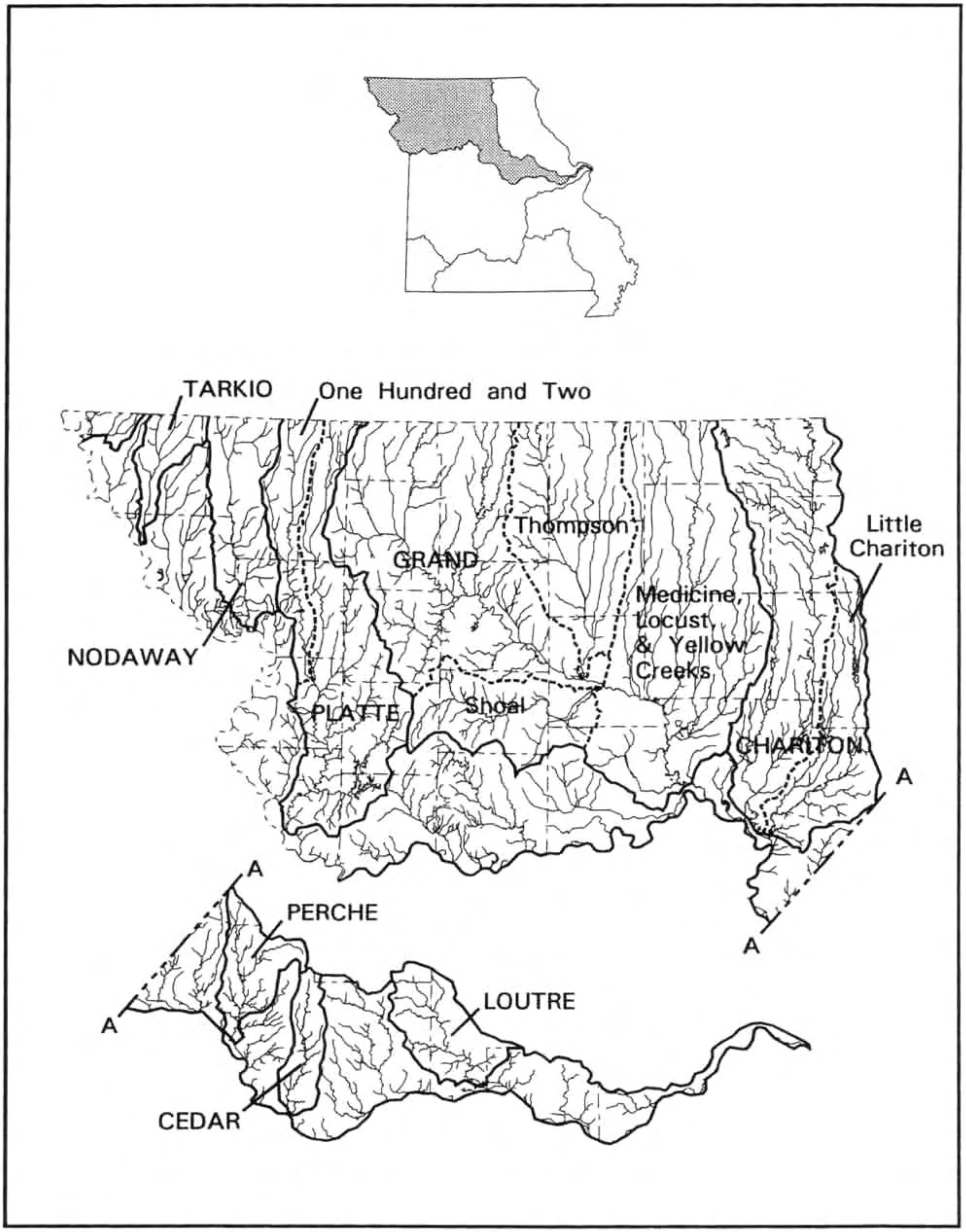

Figure 24. Missouri River tributaries north of the Missouri River.

chloride are generally present at moderate levels, but are normally less than 150 mg/l each. Runoff from agricultural areas can contribute bacteria, nutrients, and pesticides to surface streams. Wastewater discharges from towns increase bacteria levels and contribute nutrients to the streams. Discharge from abandoned, unreclaimed coal mines in the ***Chariton River*** basin adversely affect the quality of water in the receiving stream, especially during periods of low flow. Sulfate, iron, and manganese contents can be well above public drinking water standards at times.

Tarkio River

A short reach of the ***Nishnabotna River*** crosses from Iowa to the ***Missouri River*** in the extreme northwestern corner of the state, but for practical purposes the northwestern-most major Missouri River tributary in northwest Missouri is the ***Tarkio River***. The Tarkio River drains about 534 square miles in northwest Missouri in Atchison, Holt, and Nodaway counties, and an additional area of southwestern Iowa. Several decades ago, channel improvement projects straightened much of the lower reach. The mouth of the river was moved about 20 miles upstream of its former location, thus separating the main basin from 196 square miles of drainage from the ***Little Tarkio River***, its former principal tributary.

The ***Tarkio River*** is currently ungaged. Previously, there was a gaging station on the Tarkio River at *Fairfax*. Upstream from here, the Tarkio drains about 508 square miles, and average flow between 1922 and 1990 was 209 ft^3/sec (5.59 in./yr of runoff). Highest annual average flow was in water year 1987 when it averaged 677 ft^3/sec, and the year of lowest flow was water year 1934 when it averaged only 23.6 ft^3/sec. Peak recorded flow was on June 20, 1942, at 16,300 ft^3/sec; periods of no flow have occurred several years. Flow of the Tarkio at this location is greater than 4.3 ft^3/sec 95 percent of the time, and greater than 65 ft^3/sec 50 percent of the time. There are no public water supply reservoirs or public water supply surface water intakes in the Tarkio River basin in Missouri.

Nodaway River

The ***Nodaway River*** drains 1,780 square miles of southwestern Iowa and northwestern Missouri. About 586 mi^2 of the drainage is in Missouri in Nodaway, Andrew, and Holt counties. The basin is some 115 miles long, and only 10 to 12 miles wide in Missouri, making it one of the narrower basins in the state. It flows into the Missouri River in southwestern Andrew County. Much of the channel has been straightened to decrease flooding of farm land along the river.

Upstream from *Graham*, the Nodaway River drains 1,380 square miles. In the 11 year period between 1982 and 1993, flow here averaged 1,052 ft^3/sec; average annual runoff was 10.36 inches. The water year of highest average flow was 1993 when it was 2,870 ft^3/sec. The highest recorded flow occurred September 22, 1993, when discharge peaked at 90,700 ft^3/sec. In water year 1985, the year of lowest average flow, discharge averaged 320 ft^3/sec. The lowest recorded flow was measured September 9, 1985, at 23 ft^3/sec. Discharge here exceeds 67 ft^3/sec 90 percent of the time, and is greater than 456 ft^3/sec 50 percent of the time.

Flow information for a longer period of time is available from a now-discontinued gaging station near *Burlington Junction*, about 15 miles upstream from *Graham*, where the ***Nodaway River*** drains 1,380 square miles. Data were collected here from 1922 to 1983. Average flow during this period was 588 ft^3/sec (6.11 in./yr runoff). Peak recorded flow here is 46,000 ft^3/sec, which occurred October 11, 1973. Minimum recorded flow occurred August 7, 1934, when it measured only 1.1 ft^3/sec. Currently, the basin contains no public water supply reservoirs, and no public water supply intakes produce from the river or its tributaries.

Platte River

The ***Platte River*** basin consists of a 2,440 square mile area of northwestern Missouri and southwestern Iowa. In Missouri, the basin contains 1,640 square miles, and consists of two major tributaries--***The One Hundred and Two River***, and the ***Little***

Platte River. The Platte drains parts of Nodaway, Worth, Gentry, Buchanan, Clinton, Platte, Clay, Andrew, and De Kalb counties. It flows into the ***Missouri River*** about 20 mi northwest of *Kansas City*. Like many northern Missouri streams, there was extensive channel modification and straightening on the Platte River earlier in this century to help decrease flooding of adjacent farm land.

Upstream from the USGS gaging station near *Agency*, the ***Platte River*** drains about 1,760 square miles; the drainage includes the ***One Hundred and Two River***. Between 1932 and 1993, average discharge here was 976 ft^3/sec. Basin runoff averaged 7.53 in/yr. The water year of highest average flow was 1993 when it was 4,108 ft^3/sec; the lowest flow year was 1934 when it averaged 67.4 ft^3/sec. Peak flow for the site occurred July 25, 1993, at 60,800 ft^3/sec. Periods of no flow have been observed several times. Figure 25 is a flow-duration curve of the Platte River near *Agency*. Discharges greater than 21 ft^3/sec occur 90 percent of the time here, and flow exceeds 185 ft^3/sec 50 percent of the time.

The City of *Gower* in Clinton County near the Buchanan County line formerly used a 15 acre reservoir constructed on a tributary of the ***Platte River***. Currently, the town is supplied by *St. Joseph* through Andrew County PWSD #2 and De Kalb County PWSD #1.

One Hundred and Two River

The One Hundred and Two River is a major tributary of the Platte. Its headwaters are in southwestern Iowa, and it drains much of the western part of the ***Platte River*** basin. Though more than 60 miles long, the basin does not exceed about 10 miles in width in Missouri.

At *Maryville*, the One Hundred and Two drains an area of about 515 square miles. In the 58 year period between 1932 and 1990, flow here averaged 238 ft^3/sec. Annual runoff averaged 6.26 inches. The water years of highest and lowest average annual flow were 1982 and 1934, respectively, when flows averaged 656 ft^3/sec and 18.6 ft^3/sec. Peak recorded flow for the river here occurred October 12, 1973 at 25,500 ft^3/sec. Periods of no flow have occurred several times. Flow here exceeds 1.1 ft^3/sec 90 percent of the time, and 31 ft^3/sec 50 percent of the time.

The City of *Maryville* has a water intake on the ***One Hundred and Two River***. Water is pumped from the river to a nearby storage reservoir. Normally, the flow of the river is adequate to meet the needs of its users, but the reservoir is necessary to store water for use during periods of low river flow. A large reservoir that will have a surface area of about 1,009 acres was recently completed by the city (Alexander, 1995; personal comm.). The dam is on ***Mozingo Creek***, a One Hundred and Two River tributary, about 4 miles east of *Maryville*. Besides water supply, the reservoir will also be used for recreation and flood storage.

Little Platte River

The ***Little Platte River*** drains the southeastern part of the ***Platte River*** basin. ***Smithville Reservoir***, a multipurpose U.S. Army Corps of Engineers reservoir, is near the town of *Smithville* on the lower Little Platte River. It was constructed for flood control, water supply, water-quality control, recreation, and fish and wildlife enhancement. The multipurpose pool contains 144,600 ac-ft of storage. At its maximum elevation, the flood control pool contains 101,800 ac-ft of storage, and the surcharge pool contains another 182,209 ac-ft. The reservoir supplies water to the towns of Smithville and *Plattsburg*. Smithville in turn supplies Platte County Water Supply districts #2, #4, #8 and #9. Plattsburg supplies the City of *Edgerton* and Clinton County Public Water Supply districts #1, #2, and #4. In addition, Smithville has a 12 acre lake, and also pumps from the Little Platte River. Kansas City ownes much of the water-supply storage in ***Smithville Reservoir***, but is not currently using it.

At *Smithville*, 2.4 mi downstream of ***Smithville Reservoir***, the ***Little Platte River*** drains 234 square miles. Between 1965 and 1993, the river had an average discharge of 168 ft^3/sec. Flow has been regulated here since the reservoir began filling in 1977. Prior to that there were many years when periods of no flow occurred. Water years of highest and

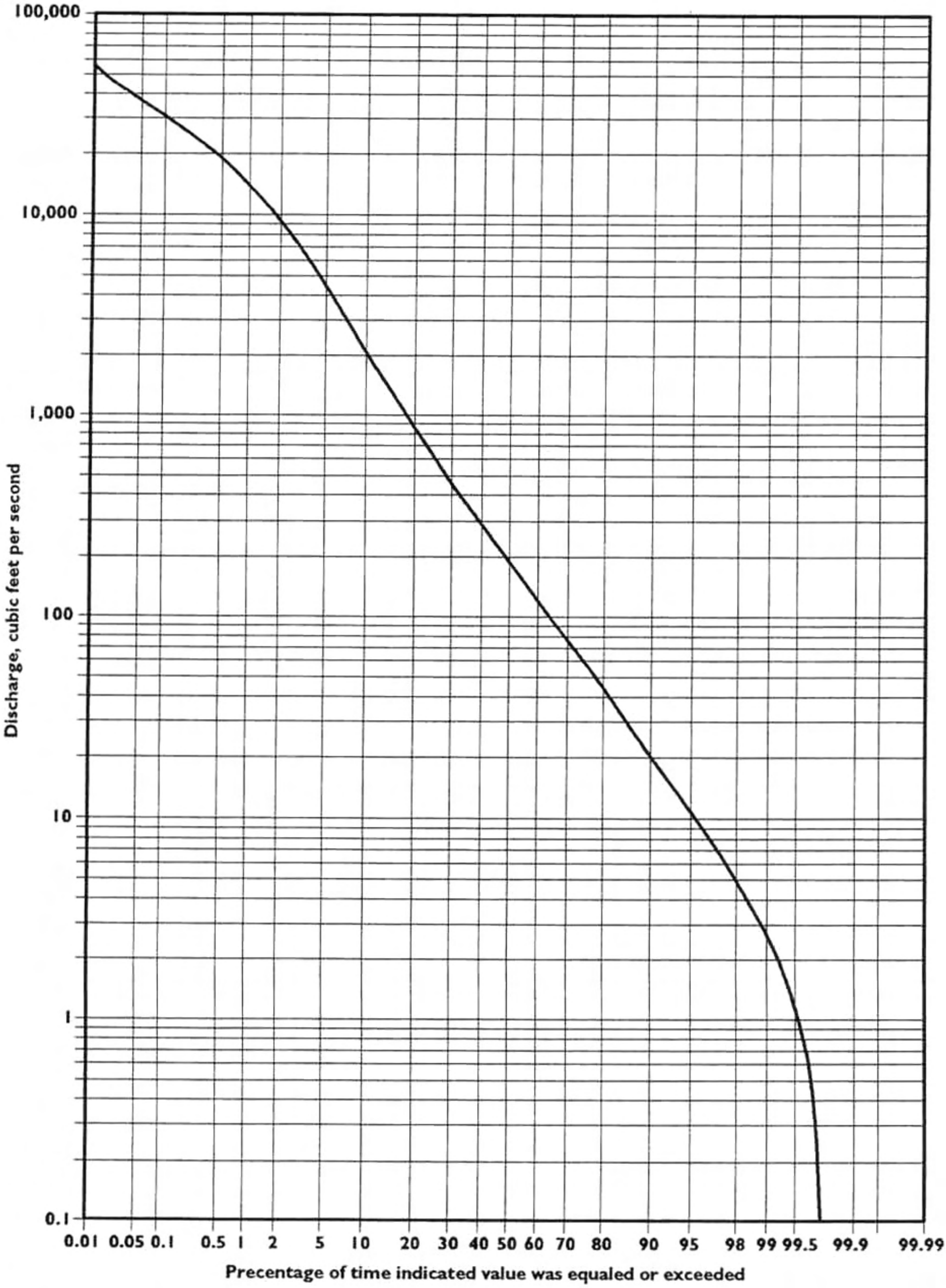

Figure 25. Flow-duration curve, Platte River near Agency, water years 1925-1993.

lowest average flows were 1993 and 1988, respectively, when discharge averaged 476 ft^3/sec and 35.4 ft^3/sec. Peak recorded flow was July 20, 1965, when discharge was 76,600 ft^3/sec. Flow here exceeds 4.8 ft^3/sec 90 percent of the time, and 27 ft^3/sec 50 percent of the time.

Grand River

The ***Grand River*** is the largest northern Missouri tributary. Rising in southwest Iowa, it drains all of Harrison, Mercer, Grundy, Daviess, and Livingston counties, and parts of Worth, Putnam, Gentry, De Kalb, Clinton, Caldwell, Carroll, Chariton, Linn and Sullivan counties in Missouri. The basin is about 150 miles long and 90 miles wide, and contains some 7,900 square miles of drainage, of which about 80 percent (6,320 square miles), is in Missouri. Much of the channel of the Grand and its major tributaries have been straightened to decrease flooding. The Grand has several major tributaries including the ***Thompson River, Shoal Creek, Medicine Creek, Locust Creek,*** and ***Yellow Creek***, all with more than 500 square miles of drainage.

Upstream from *Gallatin* in Daviess County, the ***Grand River*** drains about 2,250 square miles. Between 1921 and 1993, the river here had an average discharge of 1,228 ft^3/sec, and an average annual runoff of 7.42 inches. The water year of highest average flow was 1993 when discharge averaged 5,740 ft^3/sec. Peak recorded flow occurred the same year when it reached 89,800 ft^3/sec on July 7. Lowest average flow was in water year 1938 when it averaged 129 ft^3/sec. Lowest recorded flow was 2.0 ft^3/sec, which occurred on August 30, 1980. Figure 26 is a flow-duration curve for the Grand River at *Gallatin*. Discharge of the river here exceeds 26 ft^3/sec 90 percent of the time, and is greater than 213 ft^3/sec 50 percent of the time.

Farther downstream, near the town of *Sumner*, the ***Grand River*** drains 6,880 square miles and has a considerably higher average discharge, 4,112 ft^3/sec, based on data collected between 1923 and 1993. Average annual runoff near Sumner is 8.12 in which is slightly greater than at Gallatin. Like at *Gallatin*, water year 1993 marked the highest average annual flow, 17,390 ft^3/sec. However, the highest recorded flow at Sumner occurred June 7, 1947, at 180,000 ft^3/sec. The lowest flow water year on record was 1934 when discharge averaged 367 ft^3/sec; minimum recorded flow was 10 ft^3/sec on August 12. Figure 27 shows average daily flows for the river for water years 1993 and 1934. Figure 28 is a flow-duration curve for the river near Sumner. Discharge here exceeds 123 ft^3/sec 90 percent of the time, and 965 ft^3/sec 50 percent of the time.

The ***Thompson River*** is the largest tributary of the ***Grand River***. Draining the north-central part of the Grand River basin, it begins in south-central Iowa and joins with the Grand about 4 miles southwest of *Chillicothe*. It has a total drainage area of about 2,200 square miles, with 1,250 square miles of drainage in Missouri.

Upstream from *Trenton*, the ***Thompson River*** drains 1,670 square miles. Between 1921-1923 and 1928-1993 the river here had an average discharge of 1,021 ft^3/sec and an average annual runoff of 8.31 inches. Water years 1993 and 1934 were the highest and lowest average flow years, respectively. In water year 1993, flow averaged 3,576 ft^3/sec. Peak recorded flow did not occur in 1993—it occurred on June 6, 1947, and was 95,000 ft^3/sec. In water year 1934, average flow was 117 ft^3/sec. The lowest flow ever recorded for the river here was 1.0 ft^3/sec on May 17, 1956.

Figure 29 is a flow-duration curve for the ***Thompson River*** at *Trenton*. Discharge of the river exceeds 28 ft^3/sec 90 percent of the time, and 50 percent of the time the flow is more than 211 ft^3/sec. Like nearly all northern Missouri streams, the Thompson has a poorly-sustained base flow that shows the lack of groundwater inflow into the river.

There are several other major ***Grand River*** tributaries of significant size. ***Shoal Creek*** drains about 628 square miles of the southwestern part of the Grand River basin. It is the only significant tributary south of the Grand River. ***Medicine, Locust,*** and ***Yellow creeks*** are narrow, south-trending basins that drain the area between the Thompson basin and the ***Chariton River*** basin north of the Grand. ***Medicine Creek*** basin contains 512

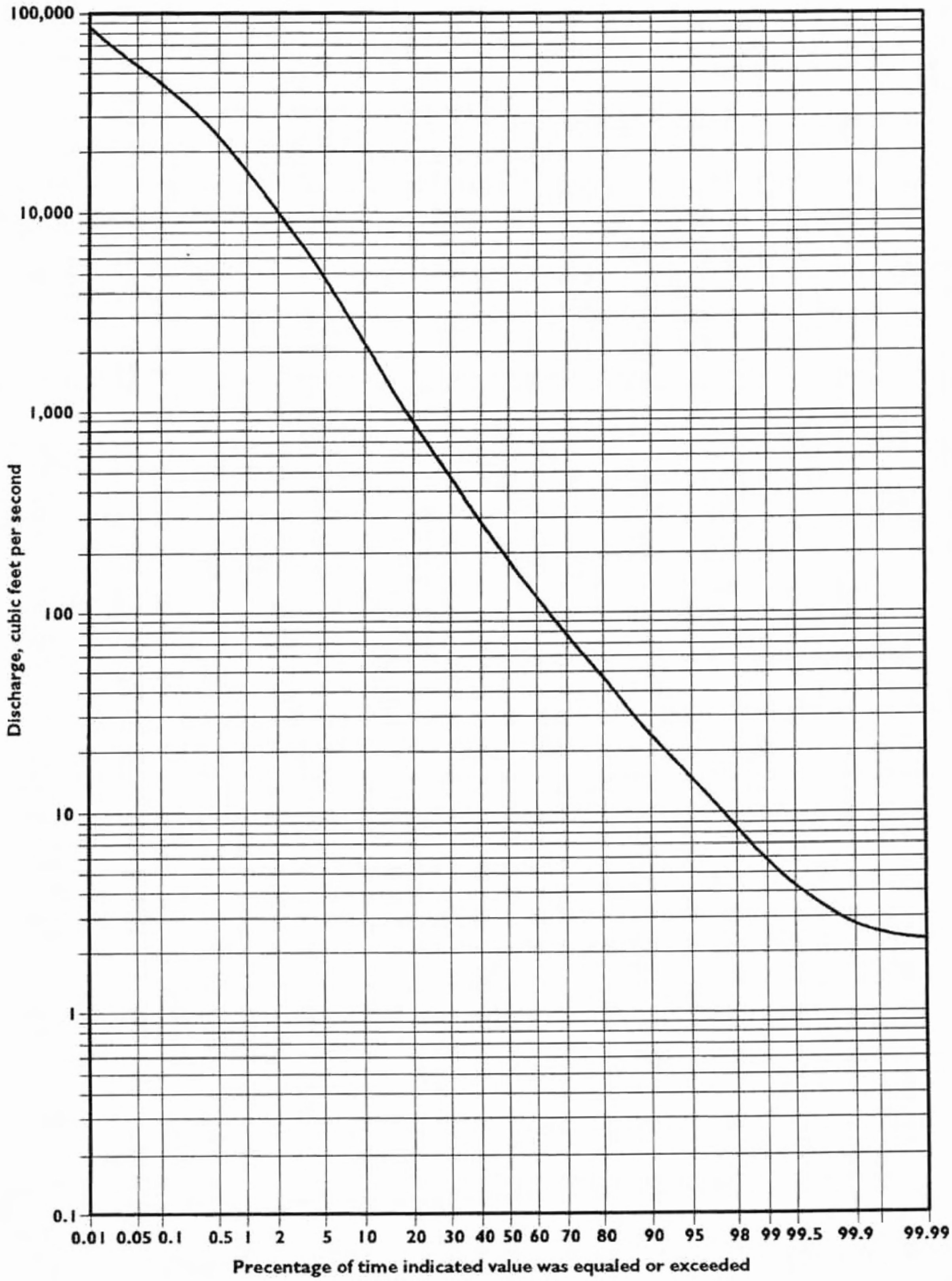

Figure 26. Flow-duration curve, Grand River near Gallatin, water years 1921-1993.

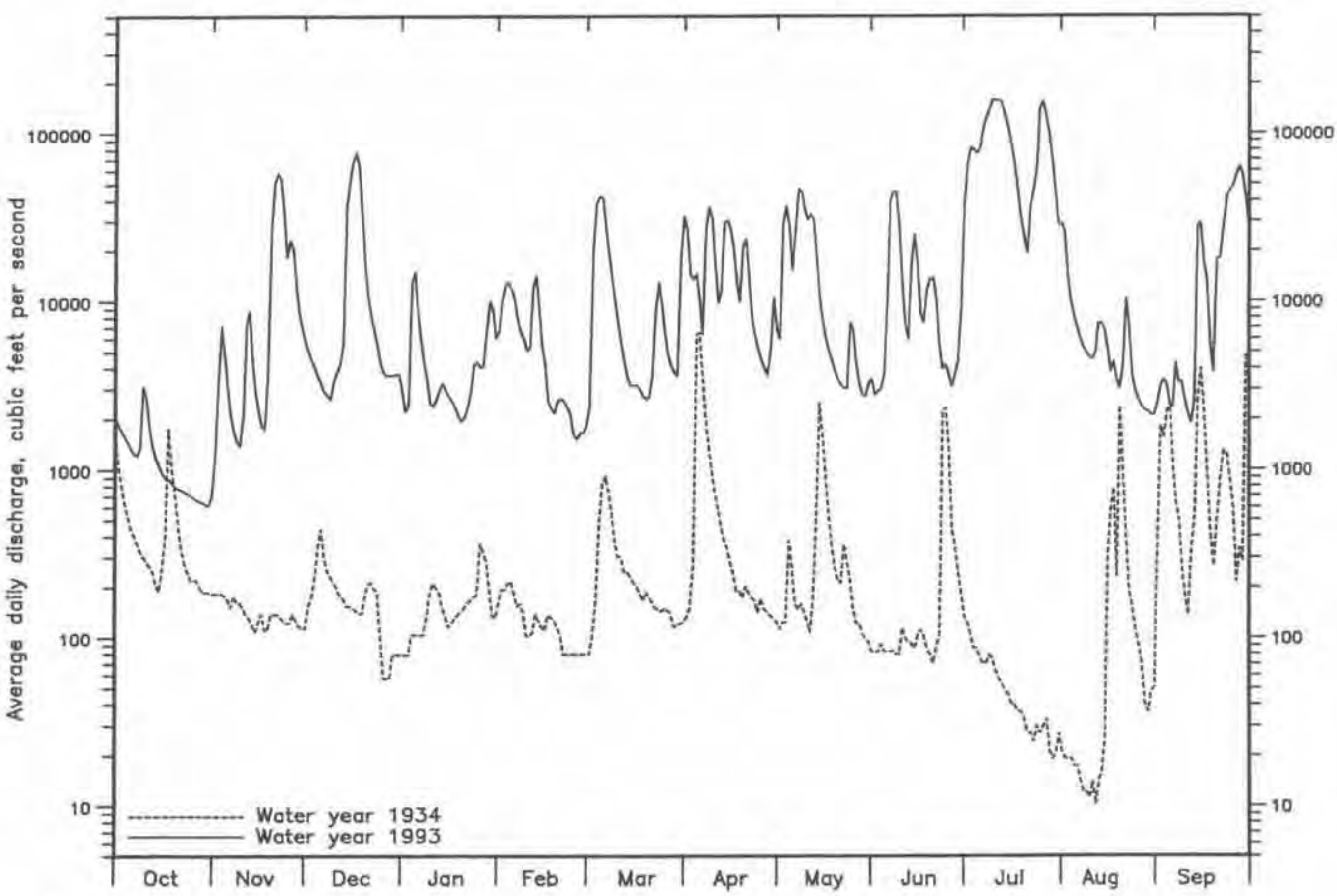

Figure 27. Average daily discharge of the Grand River near Sumner, water years 1934 and 1993.

square miles, ***Locust Creek*** 631 square miles, and ***Yellow Creek*** 593 square miles.

Numerous towns in the ***Grand River*** basin rely on surface water for their water supply, and there are a number of public water supply reservoirs. However, there are no large reservoirs in the basin.

♠*King City*, on the western edge of the Grand River basin, uses three reservoirs built on a tributary of the Grand River.

♠*Breckenridge* is supplied by an 80-acre reservoir, supplemented by a well.

♠*Cameron* uses four reservoirs with surface areas of 25 acres, 35 acres, 96 acres, and 177 acres.

♠*Maysville* has four reservoirs.

♠*Bethany* has two reservoirs with 18 acres and 78 acres of surface area, supplemented by pumping from ***Big Creek***. Also, Bethany has an intake in the new Harrison County lake.

♠*Ridgeway* has a 20-acre lake and also supplements storage by pumping into the reservoir from Big Creek and ***Rock House Lake***.

♠Harrison County PWSD #1 uses a 40-acre reservoir for water supply.

♠*Jamesport* has a 13-acre reservoir, and

♠***Lake Viking*** in Daviess County has a surface area of 550 acres and supplies the water needs of Lake Viking Subdivision.

♠*Chillicothe* formerly had an intake on the ***Grand River*** to supplement its public water supply wells, but currently uses only groundwater.

♠*Mercer* uses a 21-acre reservoir in the ***Thompson River*** basin for public water supply.

♠*Trenton* has two pump-storage reservoirs with surface areas of 103 acres and 68 acres that are filled by pumping from the Thompson River.

♠*Hamilton* has an 80-acre reservoir on ***Tom Creek*** in the ***Shoal Creek*** watershed

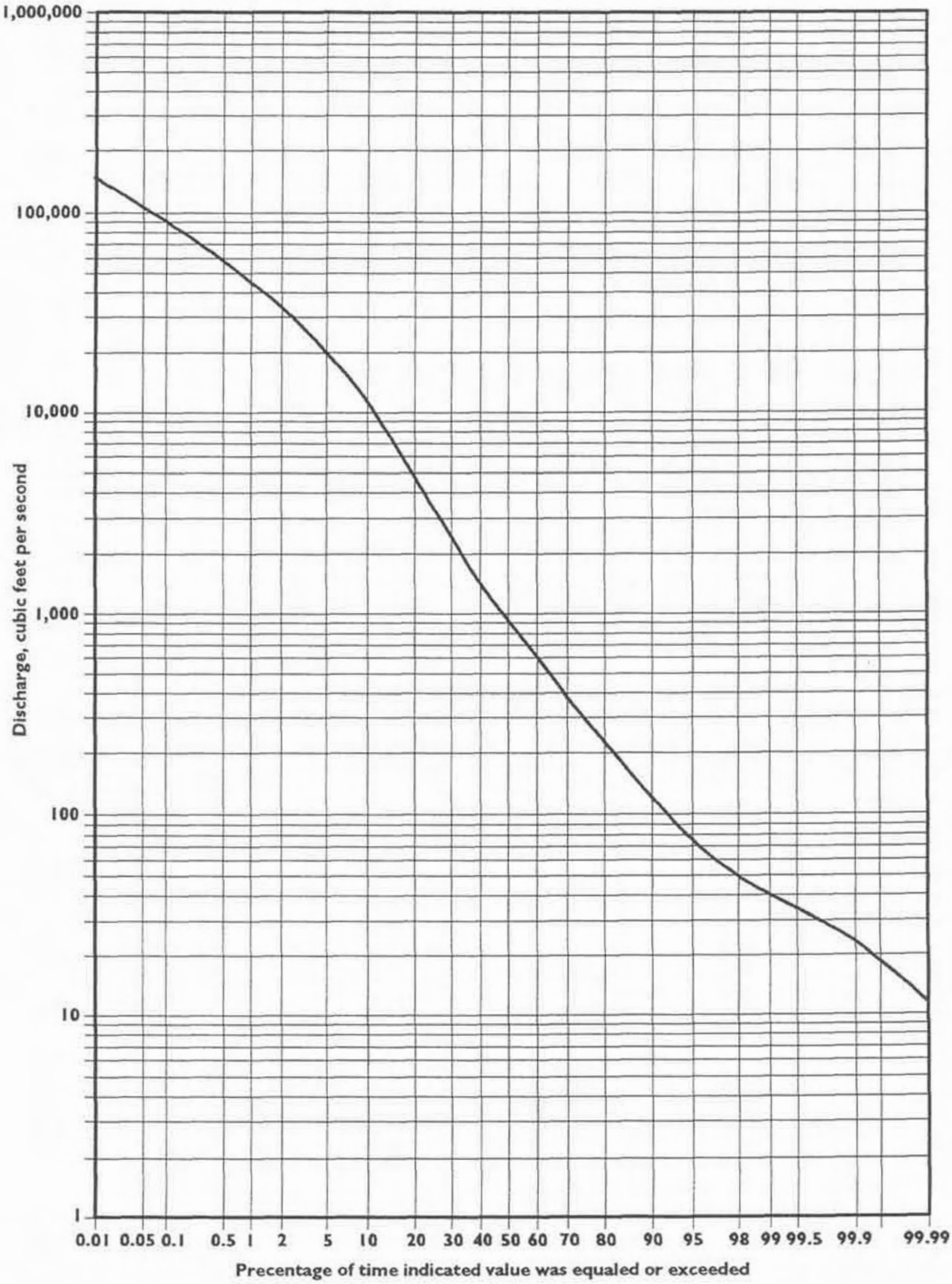

Figure 28. Flow-duration curve, Grand River near Sumner, water years 1925-1993.

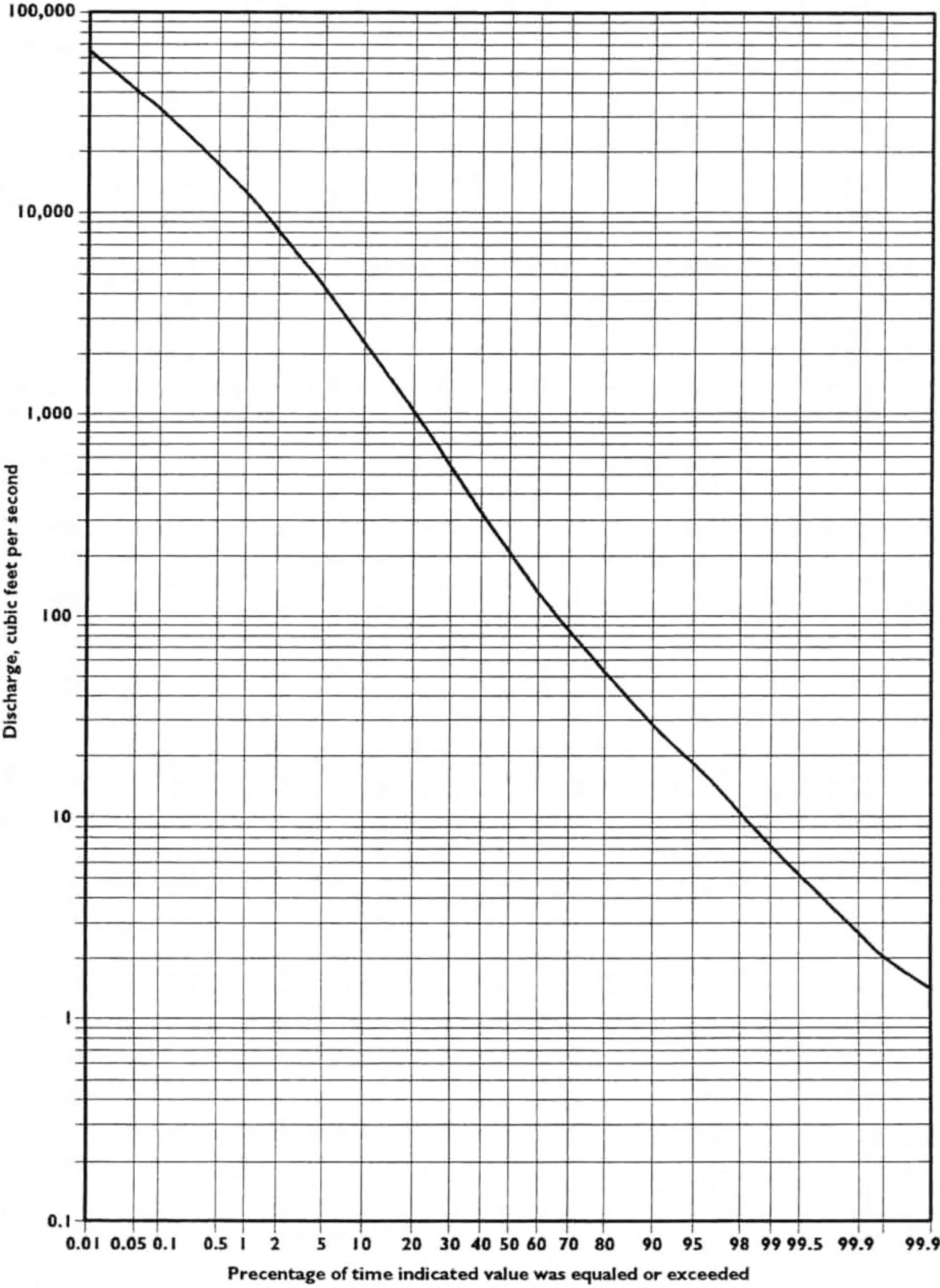

Figure 29. Flow-duration curve, Thompson River at Trenton, 1929-1993.

which it supplements by pumping from ***Marrowbone Creek.***

♦*Milan* uses two reservoirs with 13 acres and 235 acres of surface area. Both are on tributaries of ***Locust Creek.***

♦*Linneus* has a 15-acre reservoir on a tributary of Locust Creek.

♦*Brookfield* is supplied from a 120-acre reservoir impounding a tributary of ***Yellow Creek***. In addition, Brookfield pumps from Yellow Creek to three impoundments on the floodplain of Yellow Creek totalling 34 acres in surface area.

♦*Marceline* has two reservoirs, a small reservoir in the ***Chariton River*** basin and a newer 200-acre reservoir on a tributary of Yellow Creek.

In addition to the aforementioned water-supply reservoirs and numerous other privately owned lakes and ponds, there are several major waterfowl areas in the lower ***Grand River*** basin in Chariton and Linn counties. There are several large, shallow lakes in ***Swan Lake*** National Wildlife Refuge and Fountain Grove State Wildlife Management area that are used for waterfowl habitat.

Chariton River

The ***Chariton River*** is the second largest tributary of the ***Missouri River*** in northern Missouri. The basin covers parts of Schuyler, Putnam, Sullivan, Adair, Linn, Macon, Chariton, Randolph, and Howard counties.

The river rises in south-central Iowa and, like many northern Missouri streams, is long and narrow. It is some 150 miles in length and has a maximum width of about 22 miles. More than 50 percent of the channel of the ***Chariton River*** has been straightened. The mouth of the river has been diverted about 6 miles upstream to help decrease flooding in the lower reaches. However, this left its major tributary, the ***Little Chariton River***, a separate drainage. The Little Chariton flows into the river near the Chariton-Howard county line at *Glasgow*. Combined, the Chariton and Little Chariton rivers drain an area of about 2,960 square miles, of which about 70 percent (2,070 square miles) is in Missouri. All of the Little Chariton River drainage is within Missouri.

Upstream from *Prairie Hill*, the Chariton drains about 1,870 square miles. Between 1928 and 1993, the river here had an average discharge of 1,245 ft^3/sec, and an average annual runoff of 9.05 inches. The water years of highest and lowest average annual flow occurred within 4 years of each other. In water year 1993, the discharge averaged 4,320 ft^3/sec, and in water year 1989, flow averaged 166 ft^3/sec. Minimum and maximum recorded flows did not occur in either of these water years. Peak recorded discharge at this station occurred April 23, 1973, and was 31,900 ft^3/sec. Minimum recorded flow occurred August 7, 1934, and was 4.6 ft^3/sec. Figure 30 is a flow-duration curve of the Chariton River near Prairie Hill. As the graph shows, flow is greater than 36 ft^3/sec 90 percent of the time here and exceeds 350 ft^3/sec 50 percent of the time.

There are several public water supply reservoirs and one major impoundment in the ***Chariton River*** basin. ***Rathbun Reservoir***, a U.S. Army Corps of Engineers reservoir in south-central (Appanoose County) Iowa regulates the flow of the Chariton River to a significant degree, especially in the upper reaches. Completed in 1969, Rathbun provides flood control, low-flow augmentation, conservation, and recreation. At normal conservation pool level, it has a surface area of nearly 11,000 acres, and impounds about 200,000 ac-ft of water. Rathbun Reservoir supplies water to much of southcentral Iowa through water districts. The City of *Westboro* in Atchison County is supplied through one of these Iowa water districts.

Public water supplies in the basin include:

♦*Unionville* in Putnam County uses a 70-acre reservoir, plus ***Lake Thunderhead***, a 1,150-acre private lake.

♦*Kirksville* and much of its surrounding area uses ***Forest Lake***, a 703-acre reservoir in Thousand Hills State Park, and ***Hazel Creek Reservoir***, both on Chariton River tributaries in Adair County.

♦*New Cambria* in Macon County formerly used a 7-acre reservoir on ***Puzzle Creek***, a small Chariton River tributary. Chariton-Linn PWSD #3 now supplies water to *New Cambria.*

♦*Marceline* has two reservoirs, the newer of which is in the **Grand River** basin. The

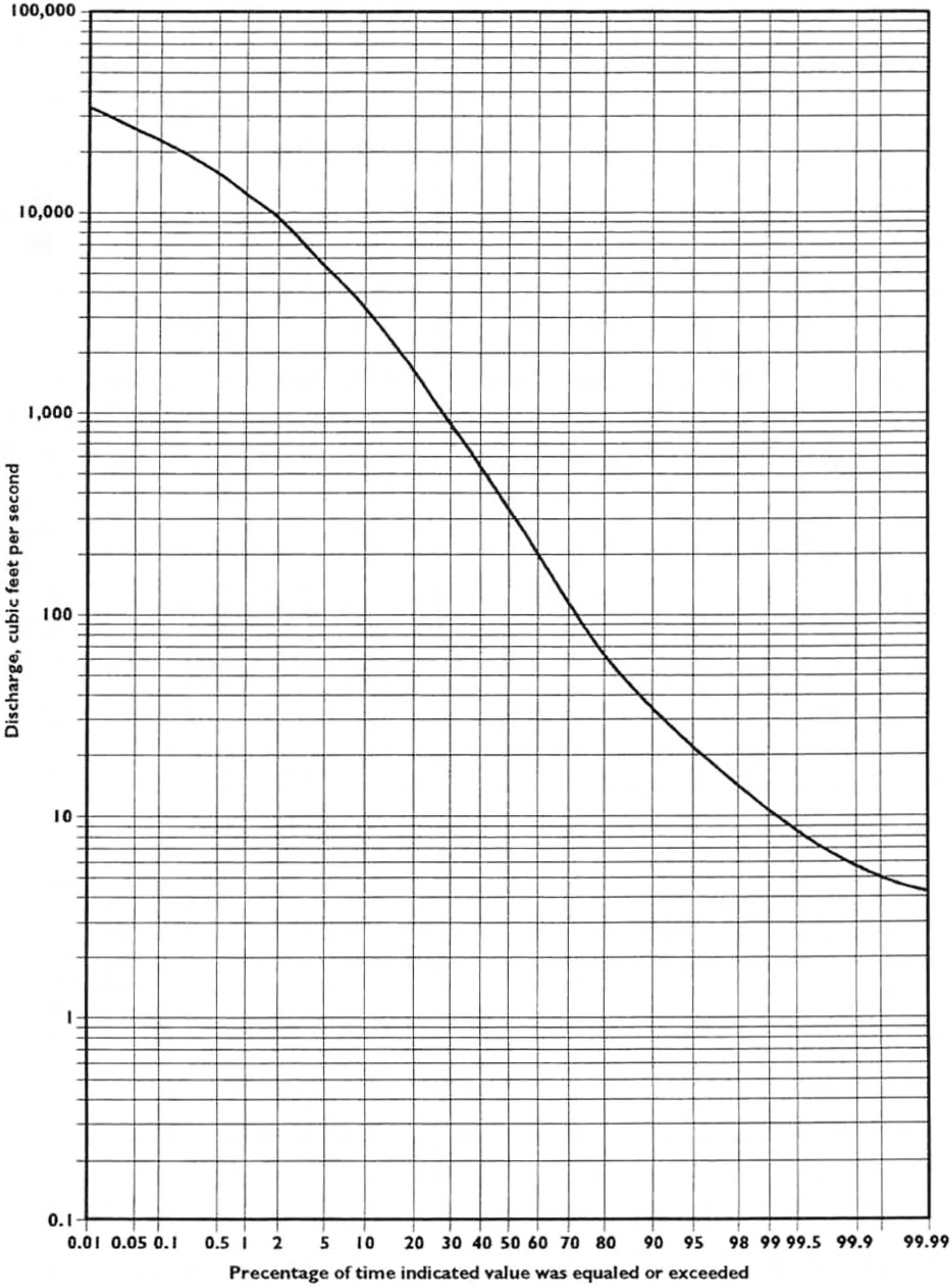

Figure 30. Flow-duration curve, Chariton River near Prairie Hill, water years 1930-1993.

older reservoir is on a tributary of ***Mussel Fork***, the major western tributary of the ***Chariton River***. The lake has a surface area of 81 acres. It is supplemented by pumping from an intake on Mussel Fork.

♦*Green City* and *Bucklin* also have reservoirs on Mussel Fork tributaries. Green City lake has a surface area of 57 acres. *Bucklin*'s reservoir is smaller, about 17 acres. Bucklin also pumps from Mussel Fork into the reservoir.

♦*Ethel* in Macon County formerly used a 23-acre reservoir for water supply, but currently obtains water from Chariton-Linn County PWSD #3.

The ***Little Chariton River*** headwaters are in Adair County south of *Kirksville*, and it drains parts of Adair, Macon, Randolph, Chariton, and Howard counties. Its two major tributaries are the ***East Fork*** and ***Middle Fork***. There is little long-term flow data available for the Little Chariton River. A gaging station near *Salisbury* in Chariton County operated between 1964 and 1970. During that time, average discharge for the 201 square miles basin was 185 ft^3/sec. Periods of no flow occurred in 1964, and peak recorded discharge was 4,550 ft^3/sec on June 13, 1966.

Today, flow in the Little Chariton is greatly affected by two major reservoirs: ***Long Branch Reservoir*** in Macon County and ***Thomas Hill Reservoir*** in Randolph County.

Thomas Hill Reservoir was formed by the damming of the ***Middle Fork Little Chariton River*** in Randolph County. The reservoir is privately owned by Associated Electric Cooperative, and is used primarily to supply cooling water for a coal-fired electric generating plant. The lake drains 147 square miles, and has a normal surface area of about 4,400 acres. It began filling in 1966. At the top of the flood pool, it impounds 85,175 ac-ft. The power plant cooling and conservation storage includes 45,900 ac-ft, and sediment storage is 14,700 ac-ft. Although it is primarily used for cooling water, it is also a source of water for Thomas Hill PWSD #1, and is used for recreation.

Long Branch Reservoir is a 2,430 acre U.S. Army Corps of Engineers reservoir formed by damming the ***East Fork Little Chariton River*** near its confluence with ***Long Branch*** in Macon County. The reservoir began filling in 1978, and is used for flood control, water-quality enhancement, recreation, and water supply. The surcharge pool contains 98,590 ac-ft of storage. The flood control pool contains 30,600 ac-ft of storage. The multipurpose pool contains 34,640 ac-ft of storage, of which 24,000 ac-ft is water-supply storage. The reservoir will supply 7.1 mgd with a 2 percent chance of deficiency from its water supply storage.

There are several smaller water supply reservoirs in the ***Little Chariton River*** basin:

♦*Macon* formerly used a 200-acre lake for water supply in addition to Long Branch Reservoir.

♦*Atlanta*, in northern Macon County, formerly used a 14-acre reservoir, but is currently supplied by *Macon*, as is the town of *Bevier*.

♦*Elmer* and *Callao* are supplied by Macon County PWSD #1, which is supplied by *Macon*.

♦*Armstrong* uses a 12-acre lake for supply.

♦*Huntsville* purchases water from CCWWC.

♦*Moberly* has three reservoirs, all on tributaries of the ***East Fork Little Chariton River***. However, only Sugar Creek Reservoir, which has a surface area of 346 acres, is currently used.

Smaller Missouri River Tributaries North of the Missouri River

Although the major ***Missouri River*** tributaries in northwest Missouri previously discussed provide most of the drainage, more than 4,000 square miles of this total area is drained by smaller rivers and streams that discharge directly into the Missouri River.

Upstream from *Kansas City*, several small watersheds including ***Rock Creek*** and ***Little Tarkio Creek***, discharge directly into the Missouri River. ***Squaw Creek*** drains through Squaw Creek National Wildlife Refuge and supplies runoff to a major waterfowl area. ***Bee Creek*** drains into the ***Missouri River*** between Kansas City and *St. Joseph*. *Dearborn* pumps from the creek into a reservoir in the upper part of the watershed and uses the water for public water supply.

Fishing River, Crooked River, and ***Wakenda Creek*** drain most of the area between the Grand River basin and the ***Missouri***

River between *Kansas City* and *Brunswick*. There are a few years of flow records available for all of these streams, but long-term flow information is not available for any of them.

Upstream from *Excelsior Springs*, the ***East Fork Fishing River*** drains only 20 square miles. Between 1950 and 1972, flow here averaged 12.9 ft^3/sec (8.76 in./yr of runoff). Maximum recorded flow was 12,000 ft^3 on July 6, 1951. Periods of no flow were observed several years. ***Crooked River*** near *Richmond* drains 159 square miles. Between 1948 and 1970, average discharge here was 98.7 ft^3/sec; annual runoff averaged 8.43 inches. Peak recorded flow here occurred July 20, 1965, when it was 29,000 ft^3/sec. Periods of no flow occurred several years. ***Wakenda Creek*** at Carrollton drains 248 square miles, and between 1948 and 1970 had an average discharge of 141 ft^3/sec (7.72 in./yr). Peak recorded flow was 7,650 ft^3/sec on September 23, 1970. Minimum recorded flow was 0.2 ft^3/sec on September 22, 1959.

Downstream from Glasgow, ***Bonne Femme Creek*** drains part of southern Randolph County and much of central Howard County, and flows into the ***Missouri River*** near *Boonville*. The City of *Fayette* uses two reservoirs constructed on tributaries of Bonne Femme Creek. Surface areas of the reservoirs are 60 acres and 185 acres.

Moniteau Creek drains eastern Howard, western Boone, and extreme southern Randolph counties. It enters the ***Missouri River*** at *Rocheport*. Discharge from an 81 square mile area of the watershed near *Fayette* was gaged between 1948 and 1969. Average flow for that period was 33.2 ft^3/sec. Maximum recorded flow was 4,330 ft^3/sec on September 13, 1961; periods of no flow occurred several years. Higbee, in the northern part of the watershed in Randolph County, uses a 15-acre lake for water supply.

Perche Creek drains a small area of southern Randolph and northeastern Howard counties, but most of its drainage is in Boone County. The creek discharges into the ***Missouri River*** southwest of *Columbia* near *McBaine*. ***Hinkson Creek***, a ***Perche Creek*** tributary draining the area south and east of Columbia, was gaged between 1964 and 1976. The watershed upstream from the gaging station contains 44.8 square miles, and discharge averaged 63.9 ft^3/sec. Average annual runoff for the period was 12.36 inches. Discharge of the creek ceased in dry weather during many years, and the highest recorded flow occurred May 15, 1970, when it peaked at 9,100 ft^3/sec.

Cedar Creek forms the county line between Boone and Callaway counties, and drains significant parts of both counties. A gaging station in the upper watershed near *Columbia* operated between 1964 and 1975. Here, the creek drains an area of about 44.8 square miles, and discharge averaged 40.7 ft^3/sec. Annual runoff for the period averaged 12.34 inches. Maximum recorded flow was 5,140 ft^3/sec on October 12, 1969, and periods of no flow were observed most years. At one time, abandoned coal strip mines adversely affected water quality in places along Cedar Creek, especially during dry weather when streamflow was low. Reclamation of the abandoned mines has essentially restored the quality of water in Cedar Creek to what it was prior to mining.

Auxvasse Creek drains most of eastern Callaway County and the southwestern corner of Audrain County. It enters the ***Missouri River*** near *Mokane*. No long-term discharge data are available for the watershed, but there is a USGS partial record station on the creek near *Steedman*. Here, the 7-day Q_2 flow is 0.1 ft^3/sec (Skelton, 1966).

The ***Loutre River*** begins in southeastern Audrain County, and flows to the southeast to join with the ***Missouri River*** near *Hermann*. It drains parts of Audrain, Callaway, Montgomery, and Warren counties. Upstream from *Mineola* near the center of the watershed the river drains 202 square miles. From 1947 to 1967 average discharge of the river here was 97.5 ft^3/sec. Maximum recorded discharge was recorded June 30, 1957 at 12,900 ft^3/sec. Periods of no discharge occurred at times in the mid-1950s. The City of *Wellsville* has two reservoirs in the upper watershed of Loutre River that provide public water supply.

MISSOURI RIVER TRIBUTARIES SOUTH OF THE MISSOURI RIVER

Missouri River tributaries south of the Missouri River drain an area of about 20,292 square miles within Missouri, or about 29.1 percent of the state (figure 31). Drainage from an additional several thousand square miles enters from Kansas. Flow characteristics of rivers within this region change significantly from western to eastern parts of the area.

The western part of the area is within the Osage Plains physiographic province. The southern extent of glaciation extends south of the ***Missouri River*** a few miles, but glacial drift south of the Missouri River in this area is generally thin. Runoff and low-flow characteristics of streams in the western and northwestern parts of the region are similar to those of streams in northwestern Missouri. Soils and shallow Pennsylvanian-age bedrock units underlying the area have low permeability, so runoff is rapid after heavy rainfall. The lack of groundwater inflow into the streams causes very low flows, or periods of no flow, during extended droughts. The eastern part of the basin is within the Ozarks physiographic province. Here, streams have well-sustained base flows provided by springs discharging from the Springfield Plateau and Ozark aquifers.

The ***Osage River*** basin has the largest number of major reservoirs and the greatest surface-water storage in the state. Four major reservoirs including ***Lake of the Ozarks, Truman Lake, Stockton Lake,*** and ***Lake Pomme de Terre,*** impound water on the Osage or its tributaries. At normal pool levels, the four contain about 4.25 million ac-ft of water, or about 1.39 trillion gallons.

Surface-water quality in this region is generally good. Most of the streams draining from the Osage Plains contain water that is a moderately mineralized calcium-magnesium-bicarbonate type. Sulfate content is moderate, and typically below 125 mg/l. Total dissolved solids content is typically below 500 mg/l. Chloride content is moderate to low, except where saline springs in the ***Blackwater River*** basin affect surface water quality. Streams draining from the Springfield Plateau generally contain water that is a calcium-bicarbonate type. Sulfate and chloride levels are typically low. Surface water in the Salem Plateau part of the region is generally a calcium-magnesium-bicarbonate type. Chloride and sulfate levels are typically low here. Streams in the northern and western parts of the region typically have greater suspended solids than those draining from the Ozarks.

Lamine River

The ***Lamine River*** drains a 2,640 square mile area of west-central Missouri in Lafayette, Saline, Johnson, Pettis, Morgan, Moniteau, Benton, and Cooper counties. The ***Blackwater River*** is the major tributary of the Lamine, and it drains about 1,550 square miles, or about 59 percent of the basin. The western part of the basin, mostly the part drained by the Blackwater River, is within the Osage Plains; the eastern area is within the Springfield Plateau part of the Ozark Plateau. The southern extent of glaciation trends east-west across the center of the basin.

The ***Lamine River***, at a USGS gaging station near *Otterville*, drains 543 square miles. The station is relatively new, so only a few years of information are available. Between 1987 and 1993, average discharge was 516 ft^3/sec, (12.91 in./yr runoff). Water year 1993 had the highest average flow, 1,464 ft^3/sec; highest flow occurred here July 7, 1993, and was 63,700 ft^3/sec. The lowest flow was 1.2 ft^3/sec on August 28, 1991. Water year 1992 had the lowest average flow, 155 ft^3/sec. Figure 32 is a flow-duration curve of the ***Lamine River*** at *Otterville*. Flow here exceeds 62 ft^3/sec 50 percent of the time, and 8.1 ft^3/sec 90 percent of the time.

Longer-term flow information is available from a now-discontinued station at *Clifton City*, a few miles downstream from the station near *Otterville*. Upstream from here, the ***Lamine*** drains 598 square miles. Between 1922 and 1971, discharge averaged 454 ft^3/sec; average annual basin runoff was 10.33 inches. Peak flow occurred June 29, 1956, at 65,500 ft^3/sec, and periods of no flow were recorded several years.

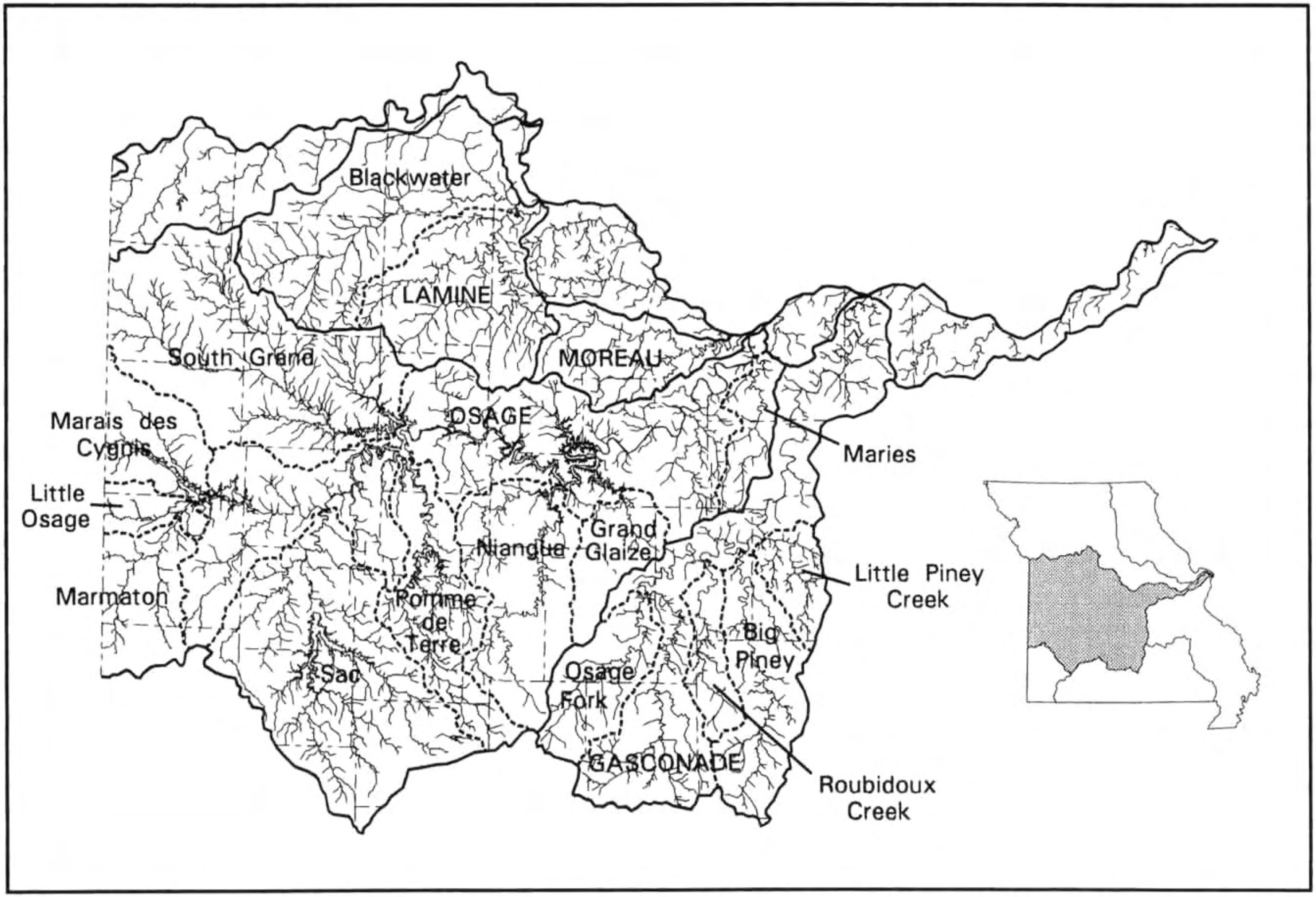

Figure 31. Missouri River tributaries south of the Missouri River.

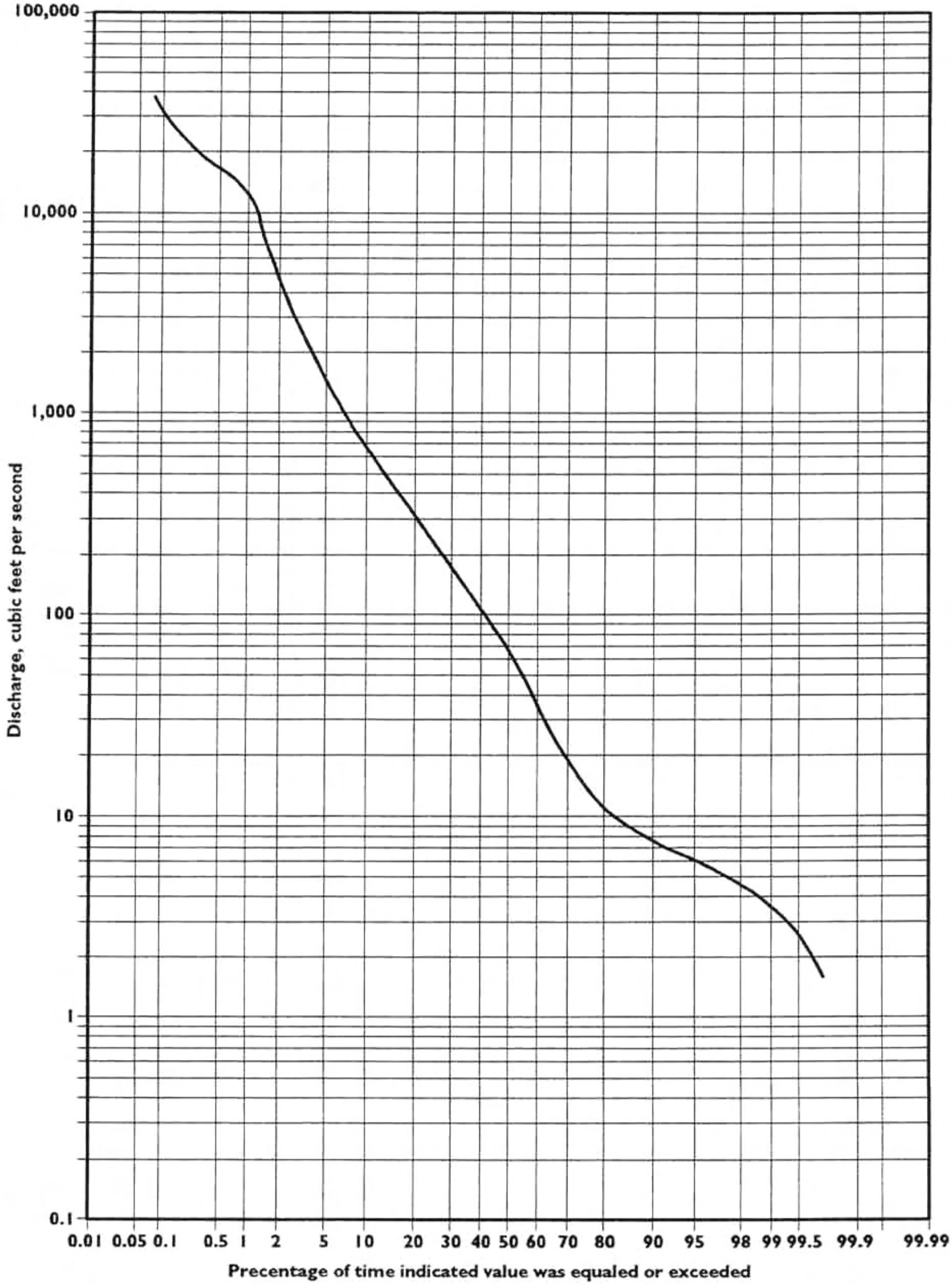

Figure 32. Flow-duration curve, Lamine River near Otterville, water years 1988-1993.

The ***Blackwater River*** at *Blue Lick* drains 1,120 square miles. Based on data collected between 1922-1933 and 1938-1993, average discharge here is 770 ft^3/sec. Annual runoff averages 9.34 inches. The water years of highest and lowest flow are 1993 and 1957, respectively, when discharges averaged 2,540 ft^3/sec and 95.8 ft^3/sec. Figure 33 shows average daily flows for water years 1993 and 1957. Peak flow here occurred November 18, 1928, and was 54,000 ft^3/sec. Flow ceased between July 17 and July 31, 1980. Figure 34 is a flow-duration curve curve of the Blackwater River at Blue Lick. Discharge here exceeds 4.0 ft^3/sec 90 percent of the time, and 50 percent of the time it exceeds 84 ft^3/sec.

Natural water quality varies with location in the basin. Generally, water in the ***Lamine River*** is a moderately mineralized, calcium-magnesium-bicarbonate type that is generally of good quality. Water quality is substantially worse in locations on the ***Blackwater River***. Saline springs discharging into the Blackwater River, especially during low river stages when there is little dilution, adversely affect the water quality. Most of these highly mineralized springs are in Saline County, and discharge from Mississippian- or Pennsylvanian-age bedrock. The water is thought to be sea water that was trapped when the sedimentary rocks were being deposited (Miller, 1971). The total dissolved solids content of these springs range from less than 500 mg/l to more than 30,000 mg/l. The water may contain high levels of sulfate, chloride, or both. At higher flows, the water in the Blackwater River is a moderately mineralized calcium-magnesium-bicarbonate type. During low-flow periods, however, the river water is a sodium- or calcium-chloride type, and total dissolved solids may exceed 1,500 mg/l (Gann and others, 1974).

Numerous communities within the ***Lamine River*** basin either use reservoirs, surface-water intakes in streams, or both, for public water supply. The fresh water-saline water transition zone crosses the Lamine basin. Most towns south of the transition zone use groundwater; towns north and west of the transition zone generally use surface water.

♦*Sedalia* uses a 178 acre reservoir on a tributary of ***Flat Creek*** in ***Lamine River*** watershed to meet some of its supply requirements. The city also pumps considerable amounts from Flat Creek to supplement water from 11 public water supply wells.

♦*Holden*, in Johnson County, formerly used three reservoirs with surface areas of 26 acres, 30 acres and 175 acres. All of the reservoirs are on tributaries of the ***South Fork Blackwater River***. Currently only the largest of these is used for water supply.

♦*Concordia* and *Higginsville* in Lafayette County use reservoirs on Blackwater River tributaries. The reservoir serving Concordia has a surface area of 245 acres. Higginsville uses a 40-acre reservoir and a 223-acre reservoir on ***Davis Creek,*** and pumps from the ***Missouri River*** into both reservoirs.

♦*Sweet Springs* in Saline County formerly pumped from the ***Blackwater River*** to two small reservoirs, but now obtains water from the City of Marshall through Lafayette County Public Water Supply District #1.

Moreau River

The ***Moreau River*** basin occupies an area of 580 square miles in the Salem and Springfield plateaus. The river drains parts of Moniteau, Morgan, Miller, and Cole counties. Upstream from a discontinued gaging station near *Jefferson City* the Moreau River drains 561 square miles. Between 1947 and 1974, the river had an average discharge of 381 ft^3/sec, and an average runoff rate of 9.22 in/yr. Peak flow here occurred October 14, 1969, and was 24,400 ft^3/sec. The lowest measured flow was on September 30, 1956, when it measured 0.1 ft^3/sec.

Osage River Basin

The ***Osage River*** basin is the largest ***Missouri River*** tributary in the state. It drains a total of about 15,300 square miles in eastern Kansas and western Missouri. Drainage in Missouri accounts for about 70 percent of the total, about 10,700 square miles. The basin is about 250 miles long and a maximum

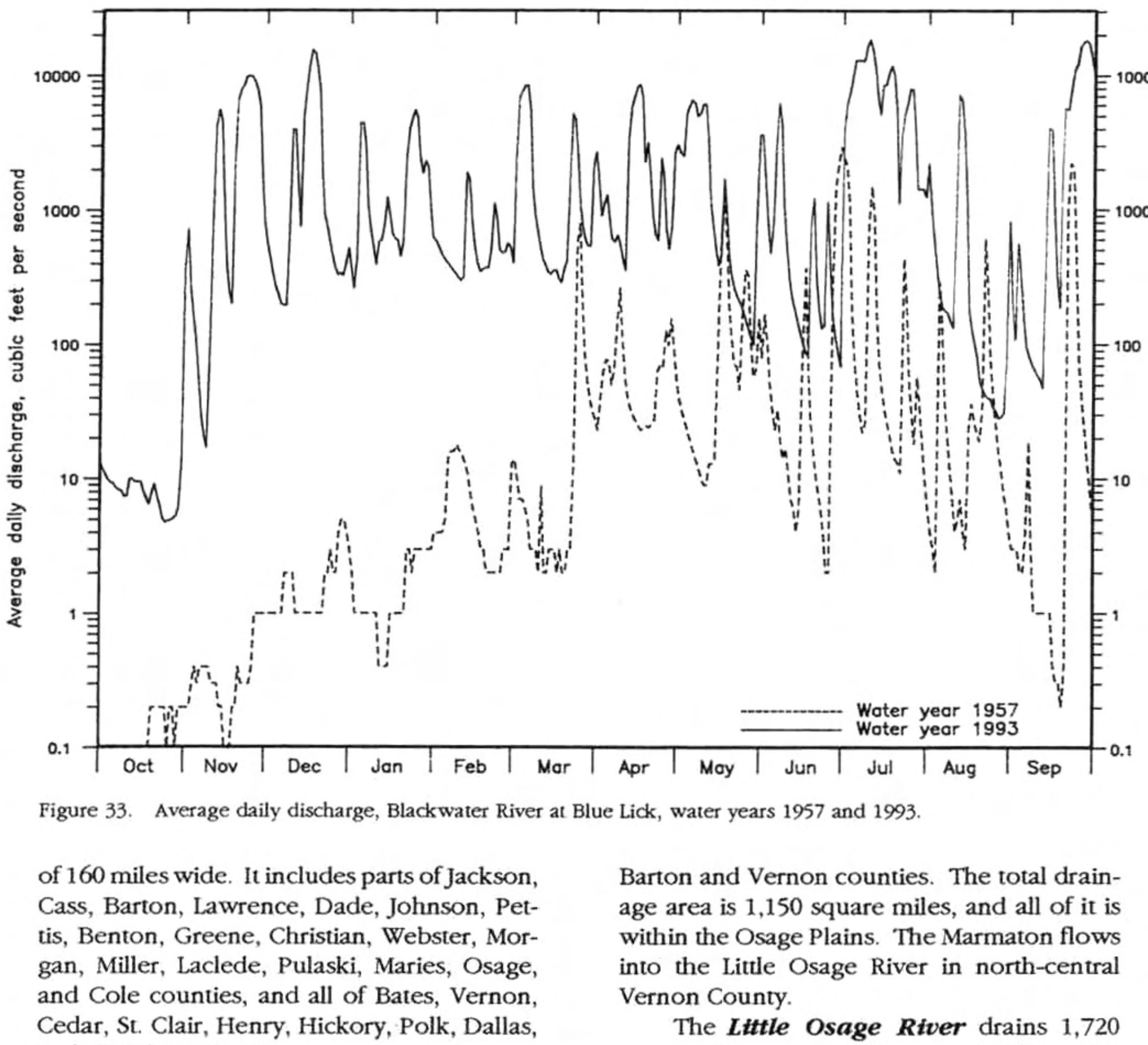

Figure 33. Average daily discharge, Blackwater River at Blue Lick, water years 1957 and 1993.

of 160 miles wide. It includes parts of Jackson, Cass, Barton, Lawrence, Dade, Johnson, Pettis, Benton, Greene, Christian, Webster, Morgan, Miller, Laclede, Pulaski, Maries, Osage, and Cole counties, and all of Bates, Vernon, Cedar, St. Clair, Henry, Hickory, Polk, Dallas, and Camden counties.

The ***Osage River*** is fed by numerous tributary rivers that contribute significant flows. The upper watersheds are within the Osage Plains. Streams here have low gradients and poorly-sustained base flows. The southern and eastern tributaries are within the Ozarks, and have higher gradients and well-sustained base flows.

Marais des Cygnes, Little Osage, and Marmaton Rivers

The upper watershed of the Osage is composed of three drainages, the ***Marais des Cygnes River, Little Osage River,*** and ***Marmaton River***. The Marmaton River rises in southeastern Kansas and drains part of Barton and Vernon counties. The total drainage area is 1,150 square miles, and all of it is within the Osage Plains. The Marmaton flows into the Little Osage River in north-central Vernon County.

The ***Little Osage River*** drains 1,720 square miles, mostly in Kansas. In Missouri it drains part of northern Vernon and southern Bates counties. It joins with the ***Marais des Cygnes River*** in northeastern Vernon County. In Kansas, the Osage River is called the Marais des Cygnes. That designation continues in Missouri to its confluence with the Little Osage River. Below that point it is referred to as the Osage River.

Productive aquifers in the upper ***Osage River*** basin typically produce highly mineralized water, therefore surface water is widely used for public water supply in this area. Several towns use reservoirs in the ***Marais des Cygnes*** basin, or pump directly from the river into storage reservoirs:

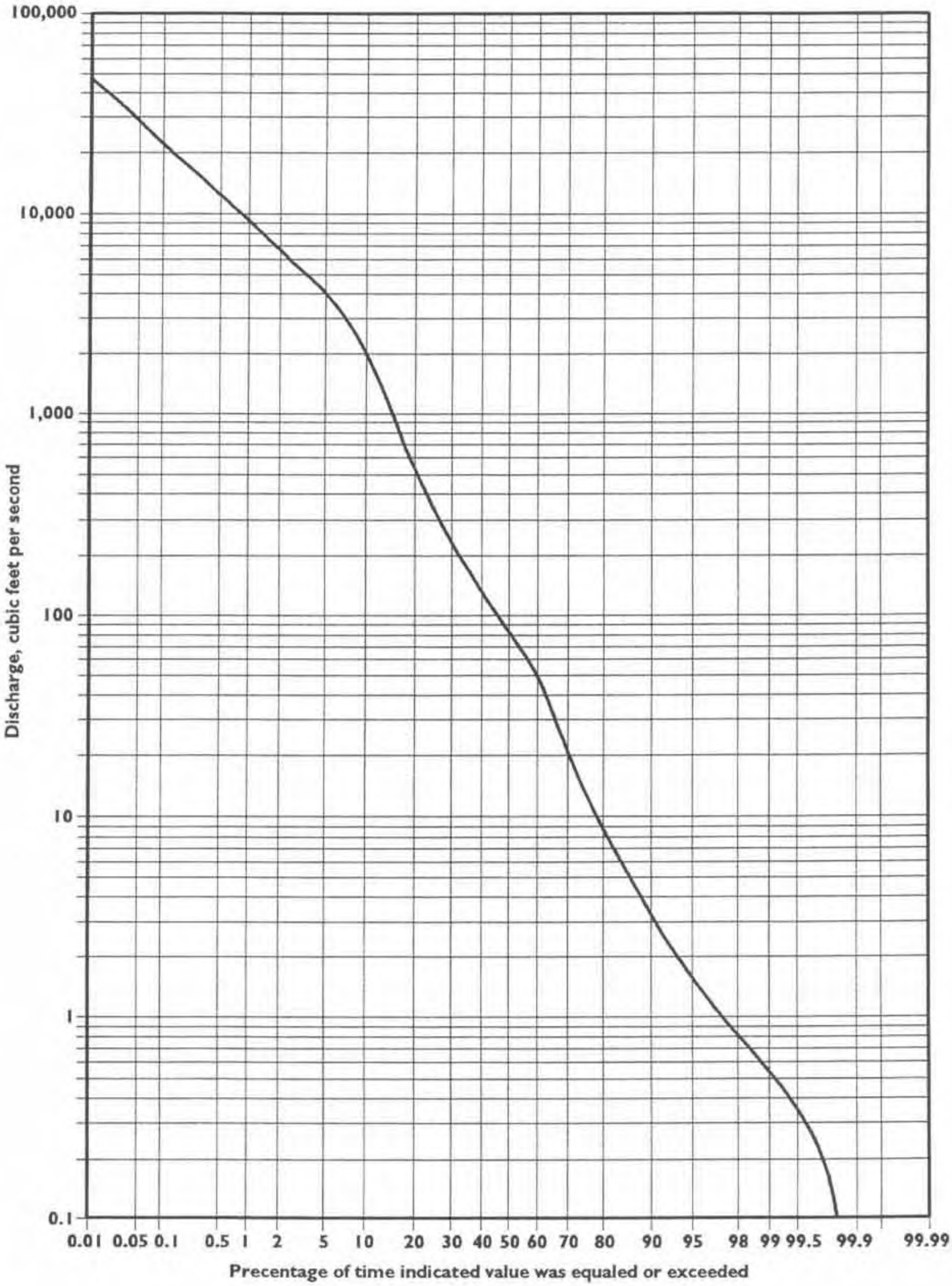

Figure 34. Flow-duration curve, Blackwater River at Blue Lick, 1922-1993.

♦Bates County PWSD #2 pumps from ***Miami Creek***, in Marais des Cygnes watershed, to a 21-acre reservoir.

♦*Appleton City* formerly used a 36-acre lake in ***Panther Creek*** basin, another Marais des Cygnes tributary. Currently, the town obtains water from Henry County PWSD #2, which is supplied from ***Truman Lake***.

♦*Butler* uses intakes in the Marais des Cygnes River and Miami Creek, and a 67-acre reservoir in Miami Creek basin.

♦*Rockville* pumps from the ***Osage River*** to a reservoir in Bates County.

♦ *Rich Hill* pumps from Bates County Ditch to an upland reservoir.

A USGS gaging station has been in operation on the ***Osage River*** above *Shell Knob* on the Bates-Vernon county line since 1979. Upstream, the basin contains 5,410 square miles. Average flow values and low-flow data are not available for this station due to backwater from ***Truman Lake*** affecting flows at low stream stages. This station is useful for obtaining medium- and high-flow information.

Sac River

The ***Sac River*** is a major southern tributary of the ***Osage River***. It rises in Christian and Greene counties and drains about 1,970 square miles. All but the lower part of the basin is within the Ozarks Plateau. The Sac River near *Dadeville*, which is upstream from ***Stockton Lake***, drains 257 square miles. Between 1966 and 1993, average discharge here was 246 ft^3/sec, and annual runoff averaged 13.03 inches. Water year 1993 was the year of highest average flow, 560 ft^3/sec. Peak measured discharge occurred September 25, 1993, when it reached 36,100 ft^3/sec. Water year 1977 was the year of lowest flow on record when discharge averaged 50.2 ft^3/sec. The lowest recorded flow for the stream here was 4.0 ft^3/sec, which occurred September 16, 1980.

Stockton Lake is the largest surface-water impoundment in the ***Sac River*** basin. The reservoir, constructed by the U.S. Army Corps of Engineers, began impounding water in 1969. Total storage at the top of the flood pool is 1,666,659 ac-ft. The multipurpose pool contains 887,109 ac-ft of storage. Benefits derived from the reservoir include flood control, hydroelectric power, and recreation. Water supply will soon be an added benefit of the reservoir. The City of *Springfield*, largest city in southwestern Missouri and third largest city in the state, is constructing a pipeline to ***Stockton Reservoir*** that will transport water to Springfield.

The flow of the ***Sac River*** below Stockton Dam is regulated by releases from the reservoir. Upstream from ***Caplinger Mills*** near its mouth, the Sac River drains 1,810 square miles. Between 1974 and 1993, flow here averaged 1,675 ft^3/sec. Annual runoff averaged 12.57 inches during the same period. In water year 1993, the year of highest recorded flow, discharge averaged 3,109 ft^3/sec. Peak flow, however, occurred on October 2, 1986, when discharge was measured at 60,000 ft^3/sec. Minimum recorded discharge, 44 ft^3/sec, was measured October 11, 1980. The water year of lowest average annual flow was 1977 when it averaged 399 ft^3/sec. Discharge of the Sac River here exceeds 91 ft^3/sec 90 percent of the time, and 986 ft^3/sec 50 percent of the time.

Pomme de Terre River

The ***Pomme de Terre River*** drains an 828 square mile area east of the ***Sac River*** basin in southwestern Missouri. The headwaters are in Webster County, and it flows into ***Truman Lake*** near *Warsaw* in Benton County. Essentially all of this basin is in the Ozarks. Part of it is in the Springfield Plateau, but most lies within the Salem Plateau.

The ***Pomme de Terre River*** near Polk, upstream of ***Pomme De Terre Reservoir***, drains 276 square miles of the Ozark Plateau. Between 1968 and 1993, discharge here averaged 284 ft^3/sec, and runoff averaged 13.99 in./yr. Water year 1993 had the highest average flow at 554 ft^3/sec. Peak flow for the stream occurred September 24, 1993, when it was 34,300 ft^3/sec. The lowest average annual flow occurred in water year 1980 when it averaged 124 ft^3/sec. The lowest recorded flow for the stream is 0.3 ft^3/sec, which was measured from August 10 to August 15, 1980. Based on recorded data, discharge of the *Pomme de Terre* here is greater than 11 ft^3/sec 90 percent of the time, while 50 percent of the time flow exceeds 89 ft^3/sec.

Pomme De Terre Reservoir near *Hermitage* lies mostly in Hickory County. It is much smaller than ***Stockton Lake***. The reservoir is a U.S. Army Corps of Engineers project. Total capacity at the top of the flood control pool is 648,700 ac-ft. Of this, 407,200 ac-ft is flood storage, 228,700 ac-ft is conservation pool storage, and 12,800 ac-ft is sediment storage. The reservoir provides flood control and recreation benefits.

Outflow of ***Pomme de Terre Reservoir*** has been measured since it began filling in 1963. Flow in the river below the reservoir has averaged 521 ft^3/sec, and average annual runoff has been 11.52 inches. In water year 1973, average discharge was its highest at 1,163 ft^3/sec. The lowest average annual flow occurred in water year 1963 when it measured 67.8 ft^3/sec. Peak flow here was 9,000 ft^3/sec on May 9,1961. Periods of no flow have occurred several times. Flow here exceeds 43 ft^3/sec 90 percent of the time, and 103 ft^3/sec 50 percent of the time.

South Grand River

The ***South Grand River*** is the major northern tributary of the ***Osage River***. Rising in eastern Kansas, the South Grand River drains 2,040 square miles of the Osage Plains. Most of the drainage, about 2,000 square miles, is in Missouri. Prior to construction of Truman Dam and Lake, the South Grand entered the Osage River near *Warsaw*. Now, about one-half of the length of the South Grand in Missouri can be affected by backwater from ***Truman Lake.***

A discontinued gaging station on the ***South Grand River*** near *Brownington* operated from 1921 to 1971. Above this point the river drains 1,660 square miles. Discharge during the period averaged 1,046 ft^3/sec. Annual runoff averaged 8.56 inches. Peak flow at this site was 63,900 ft^3/sec, which occurred November 19, 1928. Like many streams of the Osage Plains, flow ceases here during very dry weather. Another gaging station is now located on the South Grand near *Clinton*. At the new gaging site the river drains 1,270 square miles. The station is in an area that is affected by backwater from ***Truman Lake***, so flow statistics are not available for low-flow periods.

The ***South Grand*** and its tributaries are used extensively for water supply in this area.

♠*Peculiar* in Cass County formerly used a 29-acre lake for water supply. Currently the town is supplied by *Kansas City* through Cass Co. PWSD #2.

♠*Harrisonville* has two lakes with 20 acres and 285 acres of surface area.

♠*Cleveland* and *Freeman* use small reservoirs with surface areas of seven and eight acres respectively.

♠*Garden City* uses two reservoirs.

♠*Archie* and *Adrian* use reservoirs in conjunction with surface-water intakes. Both towns pump from the South Grand; Archie pumps into two reservoirs and Adrian pumps into a 26-acre reservoir.

♠Cass County PWSD #7 uses an intake on the South Grand for water supply.

♠*Pleasant Hill* and *Raymore* formerly used municipal reservoirs in the basin. *Raymore* used a 59-acre reservoir, and Pleasant Hill used a 20-acre reservoir. Raymore is now supplied by Kansas City and Pleasant Hill is supplied by Lees Summit.

Niangua River

The ***Niangua River*** rises in northern Webster County. Between the headwaters and its confluence with the ***Osage River*** in ***Lake of the Ozarks,*** it drains a 1,040 square mile area of the Ozark Plateau. In its upper reaches, the Niangua is a losing stream, and most or all of its flow during low-flow periods is lost to permeable bedrock beneath the streambed.

Perennial flow begins at about the Webster-Dallas County line. Most of the eastern tributaries of the ***Niangua River*** are also losing streams that channel surface water into the subsurface to recharge springs in the area. Additionally, springs in the Niangua basin are recharged by losing-stream drainages in adjacent watersheds to the south, southeast, and east outside of the Niangua basin. Dye tracing has shown that water in northern tributaries of the ***Osage Fork of the Gasconade River*** basin, and from ***Goodwin Hollow*** and ***Dry Auglaize Creek*** in the ***Grandglaize*** basin, provide recharge to ***Bennett Spring, Sweet Blue Spring*** and ***Hahatonka Spring***, all in the Niangua River basin (Vandike, 1992b). This natural interbasin transfer of water into the Niangua River basin increases the flow of the Niangua, while decreasing the flows of the Osage Fork and Grandglaize.

Bennett Spring discharges from a nearly vertical cave opening developed in Ordovician-age Gasconade Dolomite in the bed of Spring Hollow in Bennett Spring State Park. It is the largest spring in the ***Niangua River*** basin and third largest in Missouri. The average discharge of Bennett Spring is 177 ft^3/sec, and the lowest measured flow is 55 ft^3/sec. The flow of the Niangua River upstream from Bennett Spring during dry weather is often low, but downstream of the spring the river has a high base flow. The flow of ***Sweet Blue Spring*** combines with that of the Niangua a few miles downstream from Bennett Spring State Park near *Eldridge*. It is a much smaller spring than Bennett and averages about 15 ft^3/sec discharge. ***Hahatonka Spring*** discharges an average of about 77 ft^3/sec into the lower Niangua River. The spring is above the normal level of Lake of the Ozarks, but the Niangua River and the downstream reach of the Hahatonka Spring branch are inundated by the lake here.

The largest reservoir in the ***Niangua River*** basin is ***Lake Niangua***, which is about 7 miles southwest of *Camdenton*. Lake Niangua, completed in 1931, was constructed for hydropower. Tunnel Dam, which impounds Lake Niangua, is built adjacent to a narrow ridge. A few miles downstream of the dam are several large meanders in the river. that bring the channel back to less than 1/4 mile from the dam. A tunnel was constructed through the narrow ridge near the dam to channel water from the lake to the powerhouse. It is located a few hundred yards to the northwest, but several channel miles downstream. By doing this, the natural drop of the river, which is about 20 feet, combines with the pressure head in the lake to increase the hydropower potential. The development is owned by Sho-Me Power Corporation. Lake Niangua has a surface area of about 300 acres, and impounds about 1,200 ac-ft of water.

From 1929 to 1969, the USGS operated a gaging station on the ***Niangua River*** near *Decaturville*, a short distance downstream from ***Lake Niangua***. Upstream from the gaging station the river drains about 627 square miles. During the 39-year period of record, the stream had an average discharge of 624 ft^3/sec, and an average runoff rate of 13.6 in/yr. This runoff rate, which is higher than that of adjacent basins, probably reflects the groundwater inflow into the Niangua basin from the ***Grandglaize*** and ***Osage Fork of the Gasconade River*** basins.

Main Stem Osage River

From the eastern areas of Barton, Vernon, and Bates counties to Bagnell Dam, the ***Osage River*** flows through two large reservoirs: ***Truman Lake*** and ***Lake of the Ozarks***. Truman Lake, a U.S. Army Corps of Engineers facility, began filling in 1977, and at normal pool covers 55,600 acres (86.9 square miles). Upstream from *Warsaw*, the gradient of the river is low and relief is gentle, as is characteristic of the Osage Plains. Thus, at full flood pool, Truman covers about 209,300 acres, (327 square miles), nearly four times the area covered at normal pool level. The surcharge pool of the reservoir can store 2,911,000 ac-ft. The flood control pool will store an additional 4,006,000 ac-ft, and the multipurpose pool has 1,203,000 ac-ft of storage. Benefits provided by the reservoir include flood control, hydropower, recreation, and fish and wildlife enhancement. Henry County PWSD #2 uses ***Truman Lake*** as a raw water supply.

Flow in the ***Osage River*** below Truman Lake, which is completely controlled by releases from the reservoir, has been measured since the reservoir was completed. Between 1978 and 1993, flow averaged 11,340 ft^3/sec. Average annual runoff from the 11,500 square mile basin is 13.3 inches. High and low average annual discharges occurred in water years 1993 and 1991, respectively, when flows averaged 18,760 ft^3/sec and 2,516 ft^3/sec.

Bagnell Dam, which was completed in 1931, forms ***Lake of the Ozarks***, the largest privately owned lake in Missouri. This Union Electric facility was constructed primarily for hydropower and flood control, but has become one of the most important recreational areas in Missouri. At normal pool level, Lake of the Ozarks covers about 60,000 acres (94 square miles). In terms of surface area, at normal pool Lake of the Ozarks is the largest reservoir in Missouri. In terms of storage at normal pool, it is exceeded in Missouri only by ***Table Rock Lake***. Total storage at normal pool level is 1,927,000 ac-ft, which includes 708,800 ac-ft of dead or unusable storage.

Flow in the ***Osage River*** below Bagnell Dam is completely regulated by outflow from ***Lake of the Ozarks***. A USGS gaging station has operated here since 1880. Since 1880, average annual flow of the river has been 10,090 ft^3/sec, and annual runoff has averaged 9.79 inches. Water years of highest and lowest flows were 1927 and 1954, respectively, when discharges averaged 24,640 ft^3/sec and 1,046 ft^3/sec. Peak recorded discharge is 220,000 ft^3/sec, which occurred May 19, 1943. The lowest recorded discharge was 183 ft^3/sec which occurred on September 9, 1969. Flow here exceeds 513 ft^3/sec 90 percent of the time, and 4,020 ft^3/sec 50 percent of the time.

The ***Osage River*** above the USGS gaging station near *St. Thomas* drains 14,500 mi^2. Though the gaging station is located 38 miles downstream from Bagnell Dam, flow of the river is still greatly affected by releases from ***Lake of the Ozarks***. Between 1931 and 1993, flow here averaged 10,610 ft^3/sec. Average annual runoff is 9.94 inches. The highest average annual flow occurred in water year 1993 when it was 25,240 ft. The lowest average flow year on record was in water year 1954 when flow averaged 1,237 ft^3/sec (figure 35). Figure 36 is a flow-duration curve for the Osage River near St. Thomas. Discharge here exceeds 713 ft^3/sec 90 percent of the time, and 4,420 ft^3/sec 50 percent of the time.

Several smaller streams drain the area south of the ***Osage River*** between the ***Niangua River*** basin and the confluence of the Osage with the ***Missouri River***. ***Dry Auglaize Creek*** and ***Wet Glaize Creek*** join to form ***Grandglaize Creek*** which flows into ***Lake of the Ozarks***. Dry Auglaize Creek and its major tributary, Goodwin Hollow, are losing streams throughout most of their reaches, and water from these streams is pirated by the Niangua basin. Thus, Dry Auglaize Creek contributes little flow to the Grandglaize except during periods of high flow. Wet Glaize Creek is a gaining stream throughout much of its length, and provides most of the base flow for Grandglaize Creek. Grandglaize Creek has a well-sustained base flow provided by springs in the Wet Glaize watershed. Long-term flow information is not available, but the Grandglaize near Brumley has a 7-day Q_2 of 22 ft^3/sec (Skelton, 1966).

Tavern Creek drains northern Pulaski, eastern Miller, and western Maries counties. No long-term flow information is available for the creek, but Skelton (1966) computed the 7-day Q_2 for Tavern Creek near *St. Elizabeth* to be 2.6 ft^3/sec.

The ***Maries River*** drains a 305 square mile area south of the ***Osage River*** in western Maries and Osage counties. Between 1947 and 1970, discharge of the Maries River at *Westphalia* averaged 211 ft^3/sec, and runoff averaged 11.15 in./yr. Upstream from here, the river drains about 257 square miles of the Salem Plateau. Maximum discharge measured here was 26,100 ft^3/sec on October 12, 1969. The minimum recorded flow is 0.1 ft^3/sec, which occurred in September and October, 1956.

Gasconade River

The ***Gasconade River*** has its headwaters in Wright County, and it flows to the northeast entering the ***Missouri River*** near *Hermann* in Gasconade County. The river drains about 3,600 square miles of the Salem Plateau, and receives runoff from Howell, Wright, Texas, Webster, Laclede, Pulaski, Dent, Phelps, Maries, Osage, and Gasconade counties. The basin is about 130 miles long and about 50 miles wide in the upper part of the watershed, but it narrows to less than 10 miles wide at places in the lower reaches. The elevation of the river decreases about 700 feet over its 270 mile length. Its major tributaries are the ***Osage Fork, Roubidoux Creek***, the ***Big Piney River*** and ***Little Piney Creek***.

The ***Osage Fork*** drains 520 square miles in the western part of the upper ***Gasconade River*** basin. The main stem of the Osage Fork is a gaining stream throughout much of its length, but the watershed contains several notable losing streams. In addition, there is one stretch of the Osage Fork that loses flow into the subsurface. Losing streams on the south side of the Osage Fork, including ***Steins Creek***, appear to provide recharge to ***Big Spring*** on the Osage Fork. Losing streams on the north and west sides of the Osage Fork, however, are known to provide recharge to springs in the ***Niangua River*** basin. Dye traces in ***Brushy Creek*** and ***North Cobb Creek*** watersheds show that water lost into the subsurface here reappears at ***Bennett Spring*** in the Niangua River basin (Vandike, 1992).

A USGS gaging station on the ***Osage Fork*** at *Drynob* operated between 1962 and 1981. Upstream from here, the river drains 404 square miles, and discharge here averaged 284 ft³/sec. Maximum and minimum recorded flows are 21,300 ft³/sec, which occurred on April 12, 1979, and 7.2 ft³/sec, which was measured September 19, 1976. Average annual runoff during this period was 9.55 inches, which is considerably lower than runoff rates of similar watersheds in the area. The relatively low runoff rate probably reflects the loss of water from the Osage Fork basin into the Niangua basin.

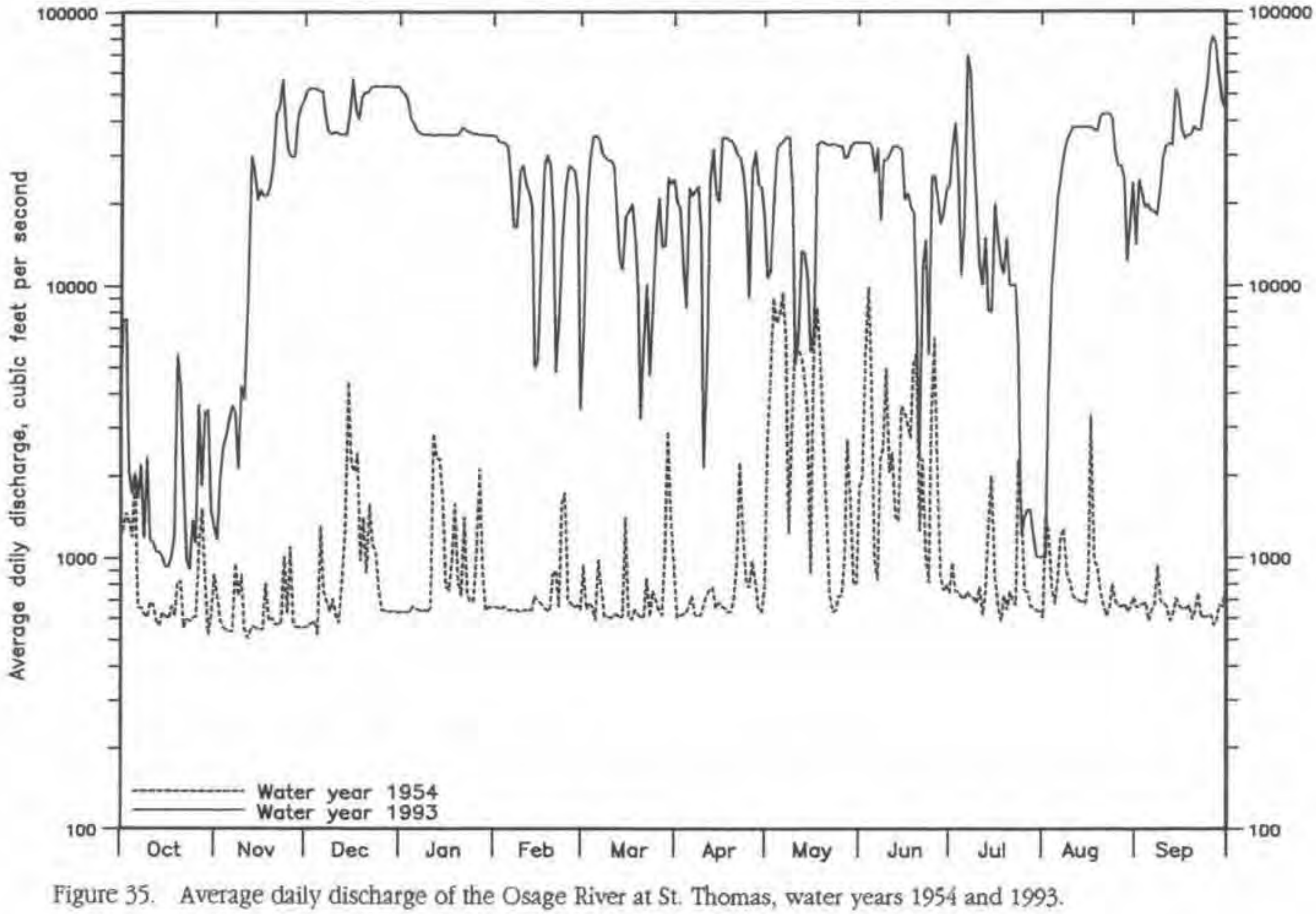

Figure 35. Average daily discharge of the Osage River at St. Thomas, water years 1954 and 1993.

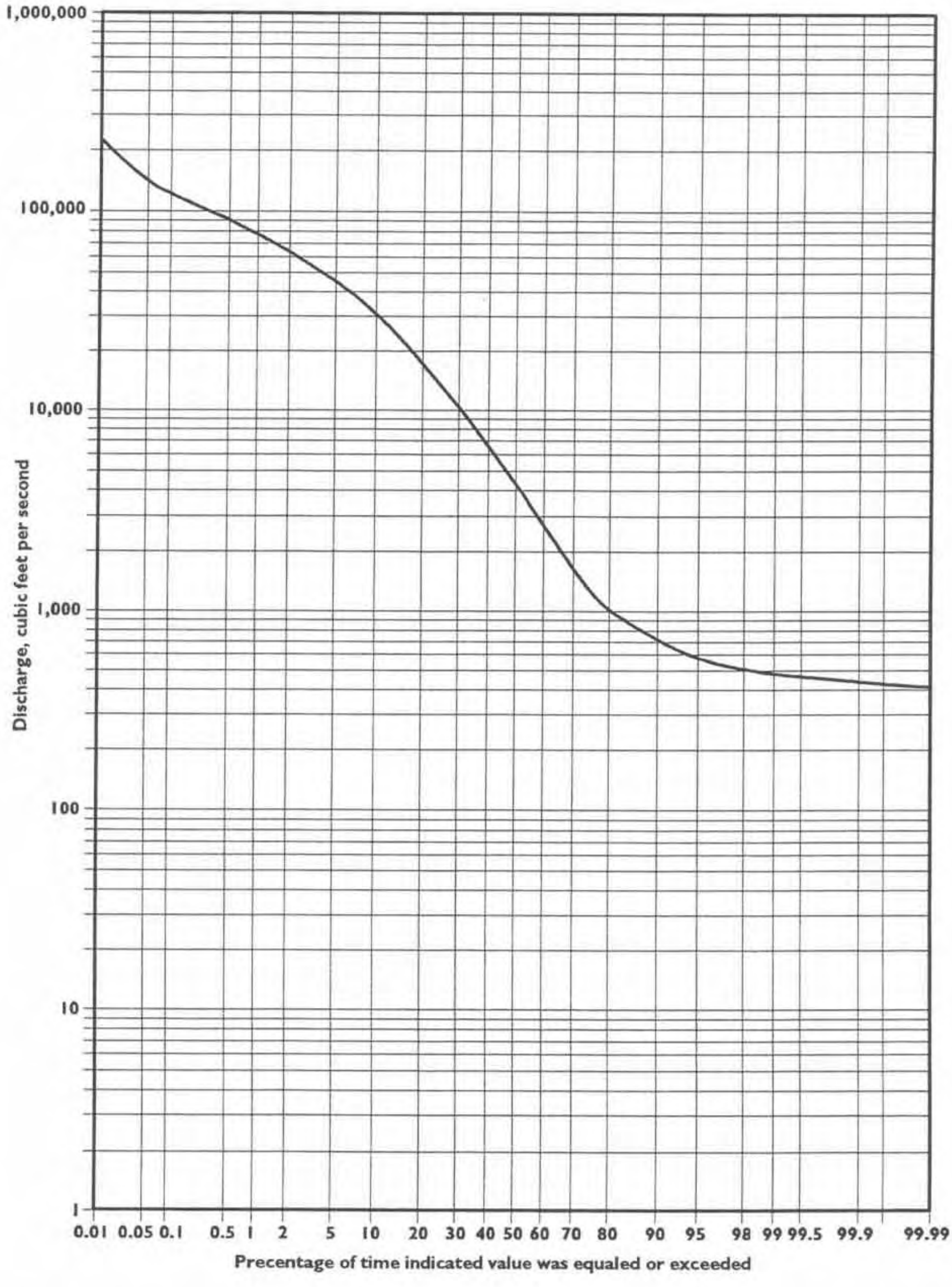

Figure 36. Flow-duration curve, Osage River near St. Thomas, water years 1932-1993.

Upstream from its confluence with the Osage Fork, the ***Gasconade River*** has a low but well-sustained base flow. There are several losing streams in the upper part of the watershed that pirate water from the upper Gasconade River basin into the ***North Fork River*** basin. Dye traces conducted from ***Wolf Creek*** and ***Fry Creek*** on the upper Gasconade show that water disappearing underground in these losing streams reappears at springs in the North Fork River basin (Williams, 1986).

Upstream from I-44 near *Hazelgreen*, the ***Gasconade River*** drains 1,250 square miles. This includes drainage from the ***Osage Fork***. The USGS operated a gaging station here between 1928 and 1971. During that period, flow averaged 965 ft^3/sec. Average annual runoff was 10.5 inches. Peak flow at this station was recorded April 14, 1945, when it was 76,400 ft^3/sec. The minimum recorded flow is 18 ft^3/sec on August 1, 1936.

Although it is a perennial stream in this reach, there is a notable loss in flow in the ***Gasconade River*** in western Pulaski County. A series of low-flow measurements by the USGS in 1953 showed that between Tie Ford and the mouth of Collie Hollow, a distance of about 13 miles, flow in the river decreased from 32.2 ft^3/sec to 2.8 ft^3/sec. In the next two miles downstream, flow increased to 69.8 ft^3/sec. Here, ***Creasy, Falling*** and ***Bartlett Mill springs*** discharge into the Gasconade River, and there are also several places where water discharges into the river from beneath the riverbed (Bolon, 1960). Fluorescent dyes injected into water disappearing into the beds of Collie, Laquey, and Trower hollows downstream of I-44 in Pulaski County reappear at Creasy, Falling, and Bartlett Mill springs, showing they are separate outlets of a single karst groundwater system (Vandike, 1992a).

Roubidoux Creek enters the ***Gasconade River*** just north of Waynesville in Pulaski County. The stream drains an area of about 300 square miles south of the Gasconade. From near its headwaters in Texas County to about the Texas-Pulaski county line, Roubidoux Creek is generally a gaining stream and has a well-sustained base flow. Between this point and Waynesville, flow in the creek is lost to the subsurface, and the creek is typically dry for a several mile stretch along the west side of Fort Leonard Wood. Flow in the creek begins again a short distance upstream from I-44, but the water that disappeared into the subsurface upstream reappears at ***Roubidoux Spring*** in Waynesville. Below Roubidoux Spring, the creek has a well-sustained base flow and provides habitat for trout.

The ***Big Piney River*** is the largest tributary of the ***Gasconade River***. It begins in extreme northern Howell County, and drains 768 square miles of the southwestern part of the Gasconade River basin. Springs along the upper and middle reaches of the Big Piney provide a well-sustained base flow.

Upstream from the gaging station near the village of *Big Piney*, the ***Big Piney River*** drains 560 square miles. Between 1921-1982 and 1988-1993, the river had an average discharge of 538 ft^3/sec. Average annual runoff for the basin for the period was 13.04 inches. Flow during water year 1927 averaged 1,179 ft^3/sec, making it the highest average annual flow year on record. Water year 1954 had the lowest average annual flow at 149 ft^3/sec. Peak recorded flow at the Big Piney gaging station was 32,700 ft^3/sec on December 27. 1942. Lowest measured flow was 69 ft^3/sec on September 17 and 18, 1954. Figure 37 is a flow-duration curve of the Big Piney River near Big Piney. Discharge here exceeds 123 ft^3/sec 90 percent of the time, and 255 ft^3/sec 50 percent of the time.

The ***Gasconade River*** basin is entirely within the Ozarks region. The availability and natural quality of groundwater here is excellent, thus towns and rural residents supply themselves through wells producing from the Ozark aquifer. There is but one surface-water supply in the basin, and that is at *Fort Leonard Wood*. Fort Wood uses an intake on the ***Big Piney River*** to supply most of the water needs of the army post.

Little Piney Creek is a small ***Gasconade River*** tributary that drains a 272 square mile area in Phelps and Dent counties. Despite its relatively small size, it has a relatively

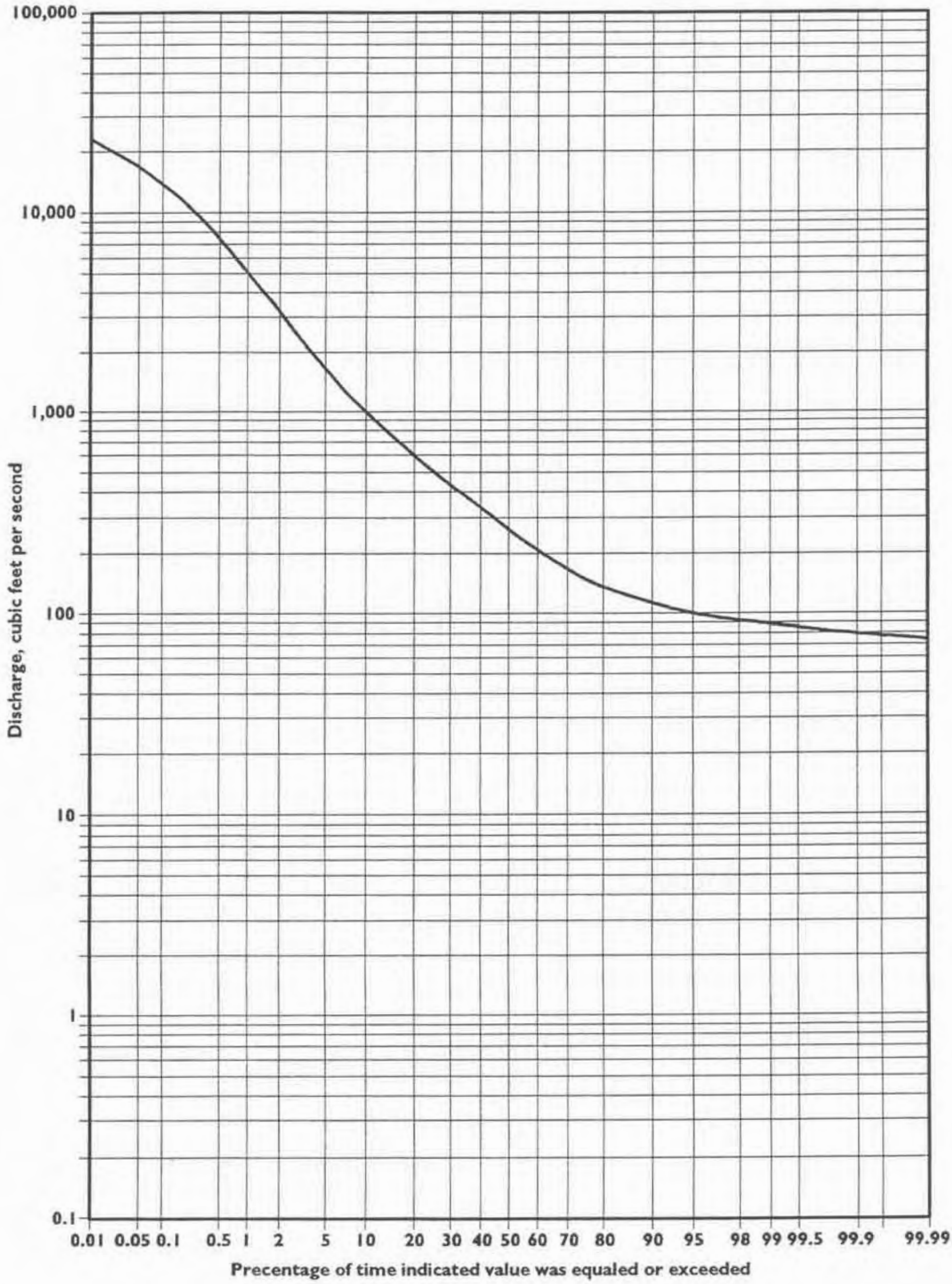

Figure 37. Flow-duration curve, Big Piney River near Big Piney, water years 1922-1993.

high, well-sustained base flow because of the numerous springs along its length. In its upper watershed, Piney Creek is a losing stream. Dye tracing has shown that water lost into the subsurface through the bed of Piney Creek east of the town of *Edgar Springs* resurfaces at ***Relfe Spring***, about 8 miles to the west in Big Piney River basin (Vandike, 1996). Despite this loss, flow from ***Piney, Finn, Lane***, and other springs is more than ample to provide well-sustained low flows.

Above the gaging station at *Newburg*, the ***Little Piney*** drains about 200 square miles, and has an average discharge of 158 ft^3/sec. Highest and lowest recorded flows here between 1928 and 1993 were 32,500 ft^3/sec, which occurred August 14, 1946, and 24 ft^3/sec, measured on June 17, 1985. Water year 1985 was the wettest year on record with an average discharge of 391 ft^3/sec. An average discharge of 47 ft^3/sec was recorded during water year 1954, the year of the lowest average flow. About 90 percent of the time the flow here exceeds 43 ft^3/sec. About 50 percent of the time the flow is about twice this, 84 ft^3/sec.

Flow of the ***Gasconade River*** has been measured at a USGS gaging station in the town of Jerome in Phelps County for the past 70 years. Although this gaging station is in the middle reach of river, about half way between headwaters and mouth, the shape of the basin causes most of the drainage to be upstream. Above here, the river drains 2,840 square miles, all but about 760 square miles of the basin. Discharge here averages 2,611 ft^3/sec and average annual runoff is 12.49 inches. Water year 1985 had the highest average flow at 6,491 ft^3/sec. Water year 1954 had the lowest with an average of 544 ft^3/sec. Maximum recorded flow was 136,000 ft^3/sec, measured December 5, 1982, and minimum recorded flow was 254 ft^3/sec, which occurred September 21, 1956. Discharge here exceeds 518 ft^3/sec 90 percent of the time, and 1,250 ft^3/sec 50 percent of the time.

Another USGS gaging station on the ***Gasconade River*** near *Rich Fountain* has operated between 1921 and 1959, and from 1986 to present. Here, the river drains an area of 3,180 mi^2, and the flow characteristics are much the same as at Jerome. Average annual discharge is 2,963 ft^3/sec, and average annual runoff is 12.66 inches. Hydrographs showing average daily discharges during the years of lowest and highest flow are shown in figure 38. Average discharge during water year 1927 was 6,560 ft^3/sec, the highest average annual flow. During water year 1954, the year of lowest flow, discharge averaged only 629 ft^3/sec. Figure 39 is a flow-duration curve for the river. As the graph shows, the river has a high, well-sustained base flow that exceeds 518 ft^3/sec 90 percent of the time, and 1,450 ft^3/sec 50 percent of the time.

SMALL MISSOURI RIVER TRIBUTARIES SOUTH OF THE MISSOURI RIVER

The previous discussion described the surface water resources of most of the ***Missouri River*** basin south of the river. There are several small watersheds that do not drain large areas, but still deserve mention.

The ***Blue*** and ***Little Blue rivers*** drain much of the area in and near *Kansas City*. Headwaters of the Blue River are in extreme eastern Kansas, and it drains much of the urban Kansas City area. The basin drains about 272 square miles of the Osage Plains in Jackson and Cass counties. A gaging station on the Blue River near *Kansas City* shows an average annual runoff rate of 11.64 inches, based on data collected between 1939 and 1993 from the 188 square mile watershed. Average discharge was 161 ft^3/sec, and minimum and maximum flows are 41,000 ft^3/sec on September 13, 1956, and zero flow at times during several years. Discharge exceeds 5.0 ft^3/sec 90 percent of the time, and 42 ft^3/sec 50 percent of the time.

The ***Little Blue River*** drains 225 square miles of the Osage Plains in Jackson and Cass counties. All of the drainage is in Missouri, and the basin contains several significant lakes and reservoirs. ***Longview Reservoir***, a U.S. Army Corps of Engineers facility on the Little Blue River, began impounding water in 1983. The watershed upstream of the dam contains

50.3 square miles. The reservoir is much smaller than those on the ***Osage River***, but still impounds considerable water. Storage of the surcharge pool is 35,370 ac-ft. The flood control pool holds 24,800 ac-ft, and the multipurpose pool contains 22,100 ac-ft. The reservoir provides flood control, water quality control, recreation, and fish and wildlife enhancement. Flow on the Little Blue River below Longview Reservoir has been monitored since 1966, several years before the reservoir was constructed. Average discharge here is 41.4 ft^3/sec, and annual runoff averages about 11.18 inches.

Blue Spring reservoir on the ***East Fork Little Blue River***, another U.S. Army Corps of Engineers project, began impounding water in 1988. This reservoir has a drainage area of 32.8 square miles, and is considerably smaller than ***Longview Reservoir***. Capacity of the surcharge pool is 3,310 ac-ft, the flood control pool holds 1,590 ac-ft, and the multipurpose pool holds 10,640 ac-ft. The East Fork of the ***Little Blue River*** has been gaged below the reservoir site since 1974. Discharge has averaged 27.6 ft^3/sec throughout the period, and annual runoff has averaged 10.9 inches.

Above the gaging station near *Lake City*, the ***Little Blue River*** drains 184 square miles. Between 1948 and 1993, flow here averaged 155 ft^3/sec, and runoff annually averaged 11.47 inches. Peak discharge at this site was 42,300 ft^3/sec on August 13, 1982. Periods of no flow have been observed several years.

Unity Village uses two reservoirs with surface areas of 15 and 23 acres to meet part of their water supply needs. Both reservoirs are in upper ***Little Blue River*** basin on a tributary of ***Cedar Creek***.

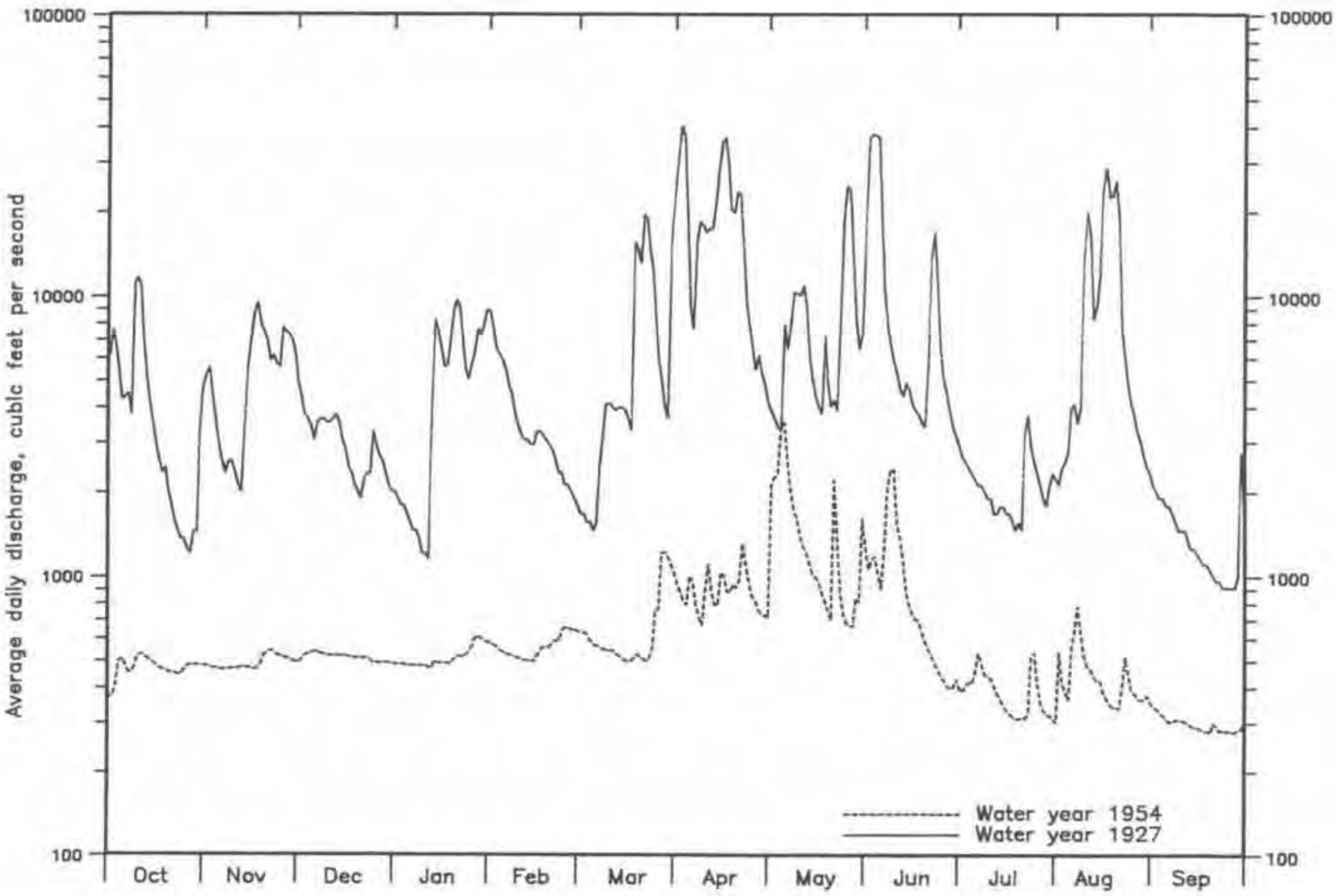

Figure 38. Average daily discharge of the Gasconade River near Rich Fountain, water years 1927 and 1954.

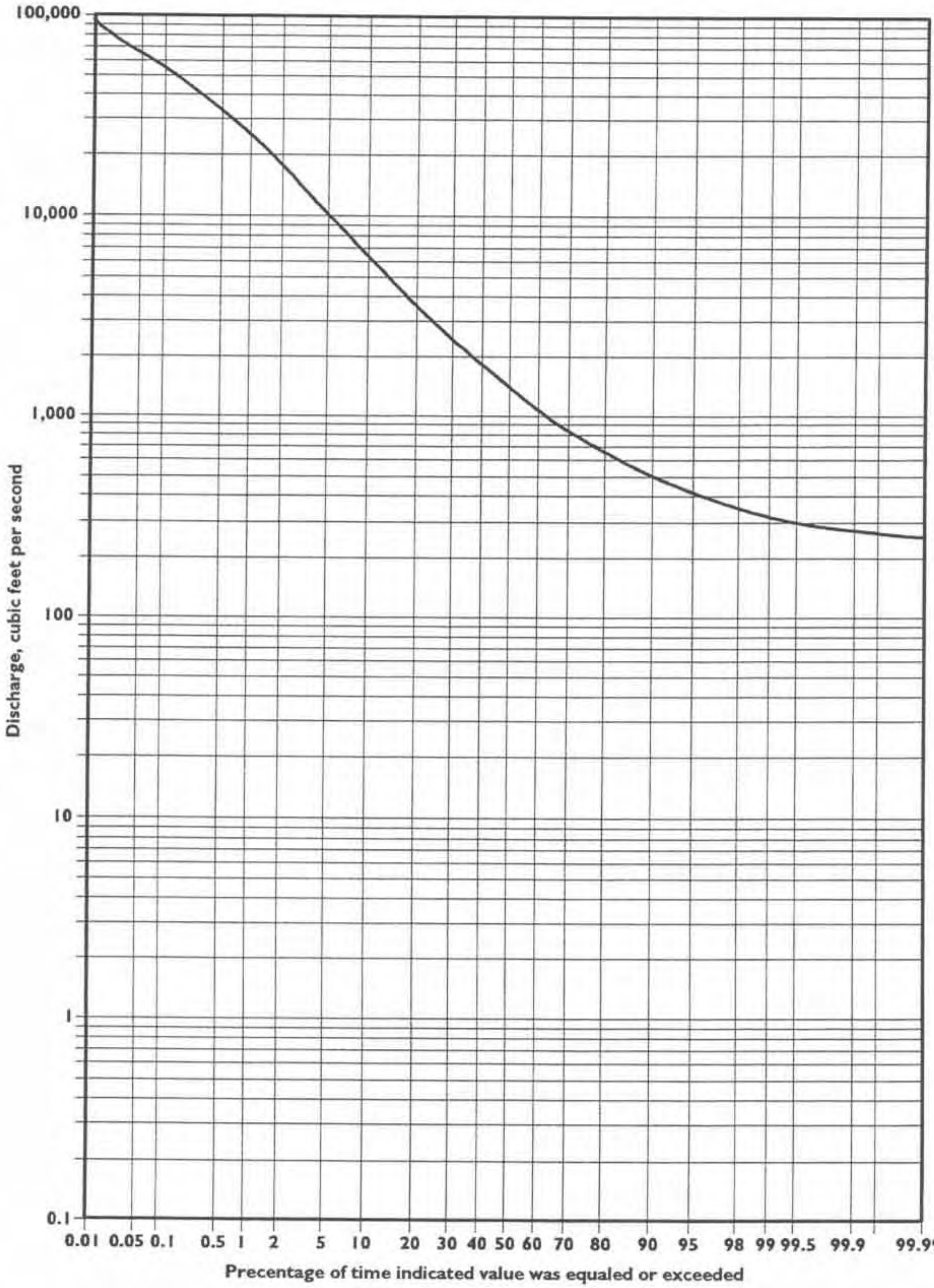

Figure 39. Flow-duration curve, Gasconade River near Rich Fountain, water years 1922-1993.

Sni-A-Bar Creek drains part of eastern Jackson County and western Lafayette County, and drains into the ***Missouri River*** at Wellington. *Odessa* in Lafayette County uses two lakes with 19 and 90 acres of surface area in the upper part of the watershed.

Petite Saline Creek drains a 182 square mile area in northern Moniteau and Cooper counties. ***Moniteau Creek*** drains the adjacent area to the east, and discharges into the ***Missouri River*** near *Marion*.

Main Stem Missouri River

The ***Missouri River*** has a drainage area of 529,000 square miles and drains parts or all of Montana, Wyoming, North Dakota, South Dakota, Nebraska, Colorado, Kansas, Minnesota, Iowa, and Missouri. In addition, it drains a small part of southern Canada. Its drainage basin comprises about 16 percent of the continental United States, and about 52 percent of the state of Missouri.

The ***Missouri River*** forms the western boundary of Missouri from the northwest corner of the state to Kansas City. It is a straight-line distance of about 116 miles, but 200 miles by river. The river then meanders east across Missouri, using about 366 river miles to cover a distance of about 240 miles. The alluvial floodplain bordering the river varies from about 2 to 8 miles wide. It is generally wider in the reach upstream from *Boonville* than in the lower reaches. Through Missouri, the river has a gradient of about 0.85 ft/mi (MGS, 1967).

Of Missouri's 114 counties, 25 border the ***Missouri River***. Based on 1990 census figures, The total population of the Missouri counties that border the Missouri River is 3,038,471, or 59.4 percent of the population of the state. The area of these counties totals 14,226 square miles, which is 20.4 percent of the state.

Considerable information is available concerning the flow of the ***Missouri River*** through Missouri. Long-term discharge information is available from USGS gaging stations at *St. Joseph, Kansas City, Waverly, Boonville,* and *Hermann*. The stations at Kansas City and Hermann have operated since 1897. Boonville has been in operation since 1925, and those at St. Joseph and Waverly since 1928. There is another station on the Missouri River at Rulo, Nebraska, 50 miles upstream from St. Joseph, that has operated since 1949.

Table 5 summarizes the discharge characteristics of the ***Missouri River*** at the long-term gaging stations in Missouri. It shows the changes in discharge, drainage area, other parameters between adjacent stations, and the differences in flow between *St. Joseph* and *Hermann*. Additionally, the table lists the main tributaries that enter the river between adjacent gaging stations.

At St. Joseph, the ***Missouri River*** drains an area of about 420,000 square miles. Average discharge here through the period of record is 41,520 ft^3/sec. Maximum recorded flow was 397,000 ft^3/sec, April 22, 1952, and minimum recorded flow was 2,300 ft^3/sec, measured on January 9, 1937. Figure 40 is a flow-duration curve of the Missouri River at *St. Joseph*. Discharge here exceeds 15,100 ft^3/sec about 90 percent of the time, and 37,000 ft^3/sec 50 percent of the time.

Average annual runoff upstream from *St. Joseph* is only 1.34 inches. This low runoff rate is primarily due to the overall low precipitation rates in the upper basin states. Average annual runoff in South Dakota, for example, varies from about 2 inches in the Black Hills to about 0.2 inches in the northeastern part of the state (SD, 1975).

The ***Missouri River*** through most of South Dakota and southern North Dakota is little more than a series of large lakes. The evaporation losses of these reservoirs are greater than the flows of many smaller rivers. The six main stem reservoirs in Montana, North Dakota, and South Dakota store about 65 million ac-ft (SD, 1975). The combined surface area of the six lakes is about 990,000 acres (COE, 1994). Assuming an evaporation rate of 24 in./yr, the losses from these lakes average about 2,735 ft^3/sec, a rate roughly equivalent to the average discharge of the ***Gasconade River*** at *Jerome*.

Station	St. Joseph	Kansas City	Waverly	Boonville	Herman	St. Joseph to Herman
River mile	448.2	366.1	293.5	196.6	97.9	
Distance between stations, miles		82.1	72.6	96.9	98.7	350.9
Drainage area, mi²	420,300	485,200	487,200	501,700	524,200	
Drainage area increase between stations, mi² (%)		64,900 (15.4)	2,000 (0.41)	14,500 (3.0)	22,500 (4.5)	103,900 (24.7)
Average discharge, ft³/sec	41,520	50,850	51,580	61,400	78,400	
Average discharge increase between stations, ft³/sec (%)		9,330 (22.5)	730 (1.9)	9,820 (19.0)	17,000 (27.7)	36,880 (88.8)
Runoff, inches.	1.34	1.42	1.44	1.66	2.03	
Runoff increase between stations, inches (%)		0.08 (6.0)	.02 (1.4)	0.22 (15.3)	0.37 (22.3)	0.69 (51.5)
Highest average annual flow, ft³/sec (year)	72,080 ('84)	102,100 ('93)	109,100 ('93)	140,500 ('93)	181,800 ('93)	
Lowest average annual flow, ft³/sec (year)	20,490 ('40)	22,300 ('34)	22,410 ('34)	23,730 ('34)	29,750 ('34)	
Instantaneous peak discharge, ft³/sec (date)	397,000 (4-22-'52)	573,000 (7-14-'51)	633,000 (7-27-'93)	755,000 (7-29-'93)	750,000 (7-31-'93)	
Instantaneous low flow, ft³/sec (date)	2,300 (1-9-'37)	1,500 (1-9-'37)	1,700 (1-9-'40)	1,800 (1-10-'40)	4,200 (1-10-'40)	
Flow exceeded 90% of time, ft³/sec	15,100	17,400	17,600	20,000	25,800	
Flow exceeded 50% of time, ft³/sec	37,000	42,000	42,200	47,000	58,100	
Years of record	1928-1993	1897-1993	1928-1993	1925-1993	1897-1993	
Major tributaries between stations		Bee Cr. Platte River Independence Cr. (KS) Kansas River (KS)	Blue River Little Blue River Fishing River Sni-A-Bar Creek Crooked River	Wakenda Cr. Grand River Chariton River Little Chariton R. Lamine River Tabo Creek	Gasconade River Bonne Femme Cr. Moniteau Cr. (N) Petite Saline Cr. Moniteau Cr. (S) Perche Cr., Cedar Cr. Moreau River Osage River Auxvasse Cr.	

Data Source: Reed and others, 1993

Table 5. Long-term flow characteristics - Missouri River in Missouri

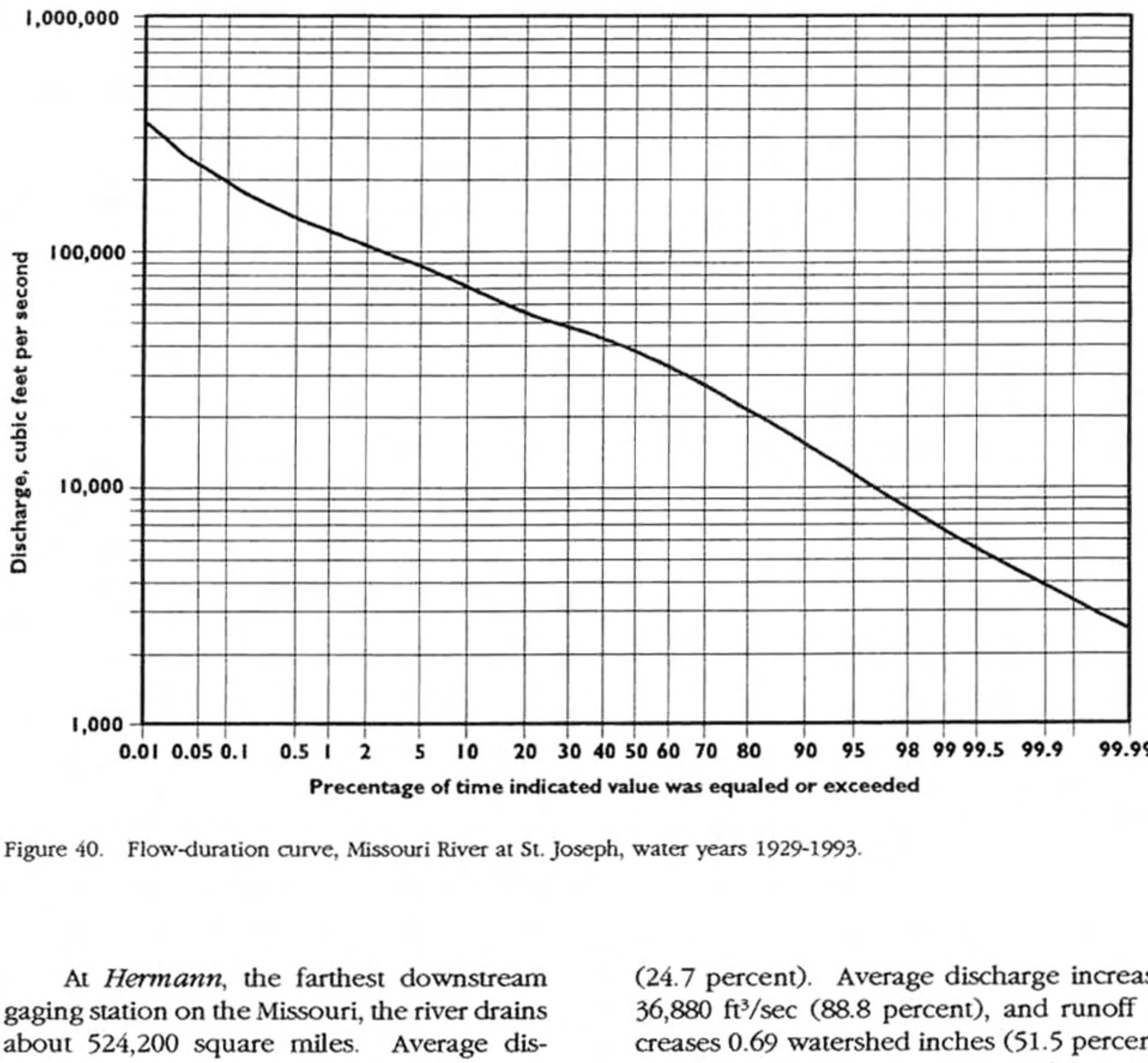

Figure 40. Flow-duration curve, Missouri River at St. Joseph, water years 1929-1993.

At *Hermann*, the farthest downstream gaging station on the Missouri, the river drains about 524,200 square miles. Average discharge here is about 78,400 ft³/sec and basin runoff is 2.03 inches. Maximum recorded flow was 750,000 ft³/sec and minimum recorded flow was 4,200 ft³/sec, respectively. Figure 41 shows the average daily discharge for the ***Missouri River*** at Hermann for water years 1993, the highest-flow year on record, and 1934, the water year of lowest flow. The average values for these two years were 181,800 ft³/sec, and 29,750 ft³/sec. Figure 42 is a flow-duration curve for the Missouri River at Hermann. Discharge here exceeds 25,800 ft³/sec 90 percent of the time, and 50 percent of the time flow is more than 58,100 ft³/sec.

Based on discharge records for the section of river between *St. Joseph* and *Hermann*, a distance of about 351 river miles, drainage basin size increases 103,900 square miles (24.7 percent). Average discharge increases 36,880 ft³/sec (88.8 percent), and runoff increases 0.69 watershed inches (51.5 percent).

The ***Missouri River*** is used as a raw-water source for several public water supplies including *St. Joseph, Kansas City, Lexington, Higginsville, Glasgow, Boonville, Jefferson City, St. Charles, St. Louis,* and *St. Louis County*. These supplies produce an average of about 258 mgd from the river to help meet the water-supply needs of a population of about 1,751,600, which is 34 percent of the population of Missouri. In addition, many other towns use wells drilled into the Missouri River alluvium which is in part recharged by the Missouri River.

LOWER MISSISSIPPI RIVER TRIBUTARIES

Surface water entering the ***Mississippi River*** downstream from *St. Louis* drains from

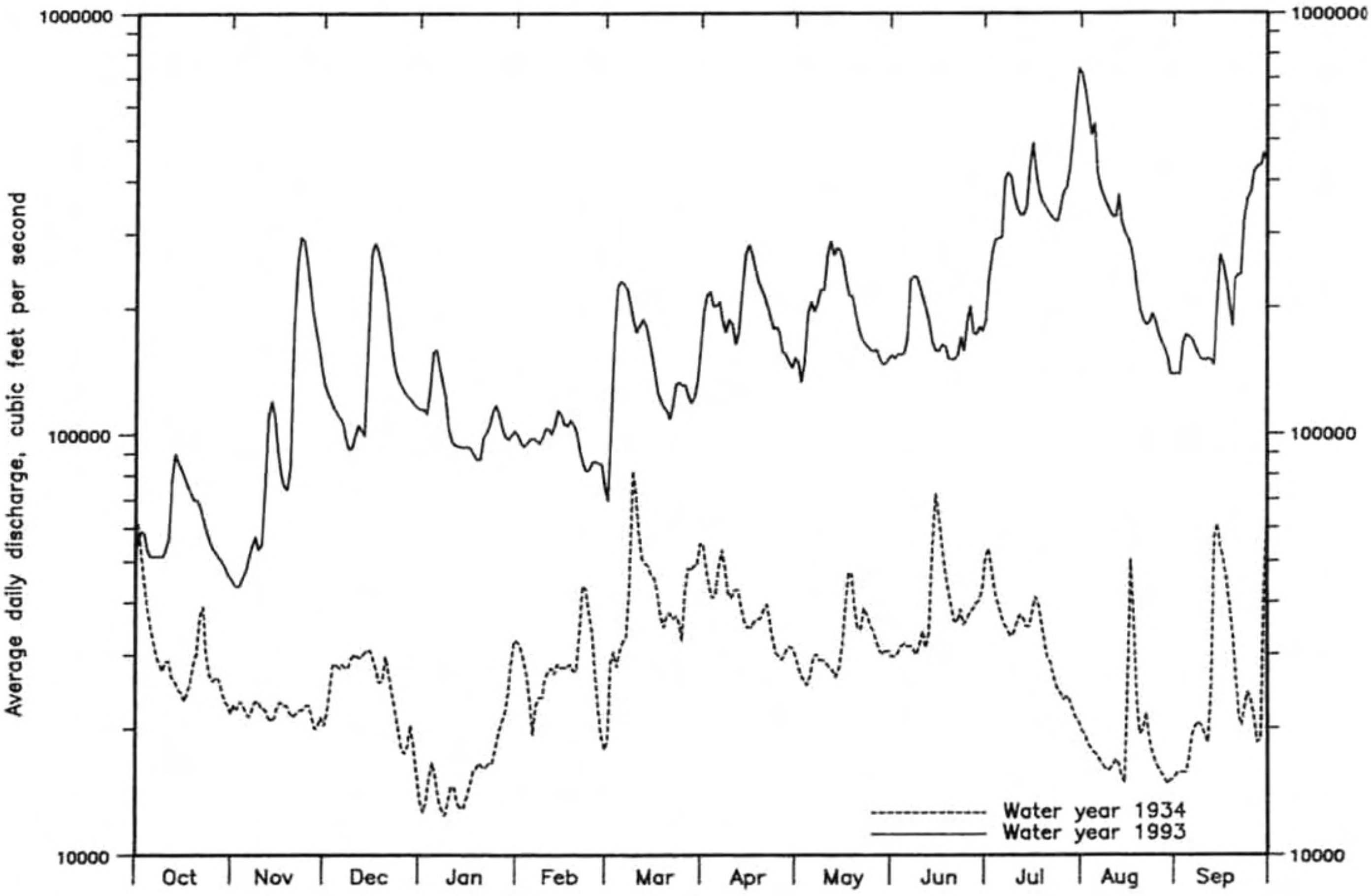

Figure 41. Average daily discharge of the Missouri River at Hermann, water years 1934 and 1993.

the northern and eastern flanks of the Ozark uplift (figure 43). The region contains about 11,825 square miles, and accounts for about 17 percent of the surface area of Missouri.

In the northern part of the area, drainage is through the ***Meramec River*** basin. Between the mouth of the Meramec River and Cape Girardeau, relatively small drainages channel surface-water runoff into the ***Mississippi River***. South of Cape Girardeau, the Mississippi enters the Southeastern Lowlands. Drainage here has been extensively modified to facilitate draining several hundred square miles of swamps in the part of the Southeastern Lowlands known as the Missouri Bootheel.

Drainage north of the Bootheel that formerly flowed into and through the Southeastern Lowlands has been diverted to the east to the ***Mississippi River*** at the northern end of the lowlands. Swamps in the Southeastern Lowlands were drained by a series of drainage ditches that channel the water south and west into Arkansas, and into the Mississippi River. The Little River Drainage District is the management unit responsible for controlling surface water flow in this area. The ***St. Francis River***, which also contributed to drainage problems in the Bootheel, has been dammed at the edge of the Ozark escarpment. ***Wappapello Lake*** impounds water during high flow periods, and releases it during drier weather.

The chemical quality of water from streams in this area is generally good. The water is typically a calcium-magnesium-bicarbonate type, and is moderately mineralized. Total dissolved solids are typically less than 400 mg/l, and chloride and sulfate are typically less than 100 mg/l. Suspended solids and bacteria content of some of the rivers is high, especially during high-runoff periods.

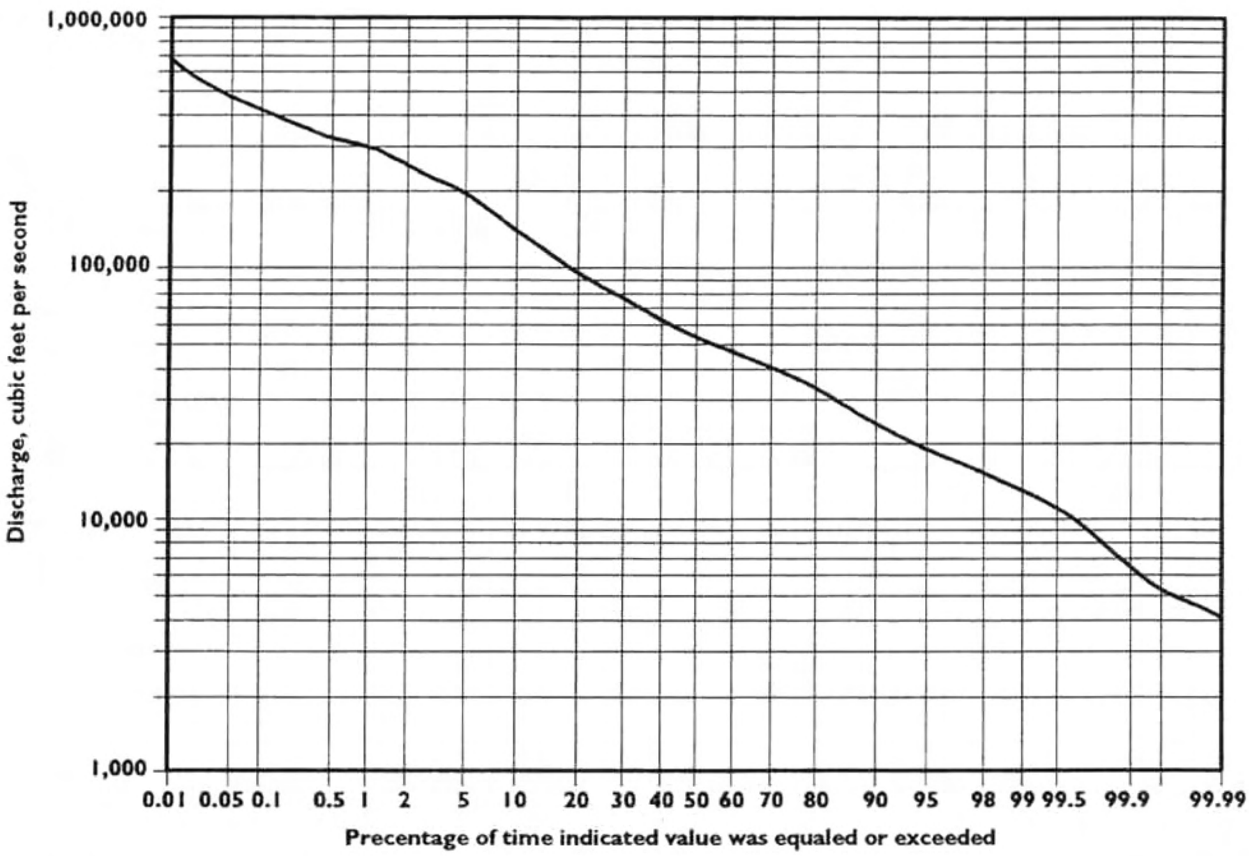

Figure 42. Flow-duration curve, Missouri River at Herman, water years 1929-1993.

Meramec River

The ***Meramec River*** drains 3,980 square miles of the Salem Plateau along the northern and western flanks of the Ozark uplift. The river drains parts or all of Dent, Phelps, Crawford, Reynolds, Washington, Iron, St. Francois, Ste. Genevieve, Maries, Gasconade, Franklin, St. Louis and Jefferson counties. Its entire drainage is in Missouri. Elevations in the upland areas reach about 1,500 ft msl in the St. Francois Mountains, and where the Meramec flows into the Mississippi River, the elevation is about 450 ft.

In the ***Meramec River*** basin, as well as most of the Ozarks, there is considerable interaction between surface water and groundwater. Most of the rivers have high, well-sustained base flows provided by groundwater primarily entering the streams from springs. There are thousands of springs in the Ozarks, some with average discharges greater than the flows of many northern Missouri rivers. Other streams in the Ozarks, some with more than 100 square miles of drainage, carry water only after heavy rainfall and are typically dry, many from their headwaters to their mouth. Water disappearing into the subsurface along these losing streams travels through well-integrated conduit (cave-like) systems that transport the water to the receiving spring or springs. Additional surface-water runoff enters the subsurface in sinkholes, which are topographic depressions in the land surface resulting from the subsurface removal of soil and rock. Sinkholes are common in the Ozarks and are an important groundwater recharge feature, but except for a few areas, the recharge from sinkholes is minor compared to that from losing streams. Considerable groundwater recharge results from rainfall percolating down-

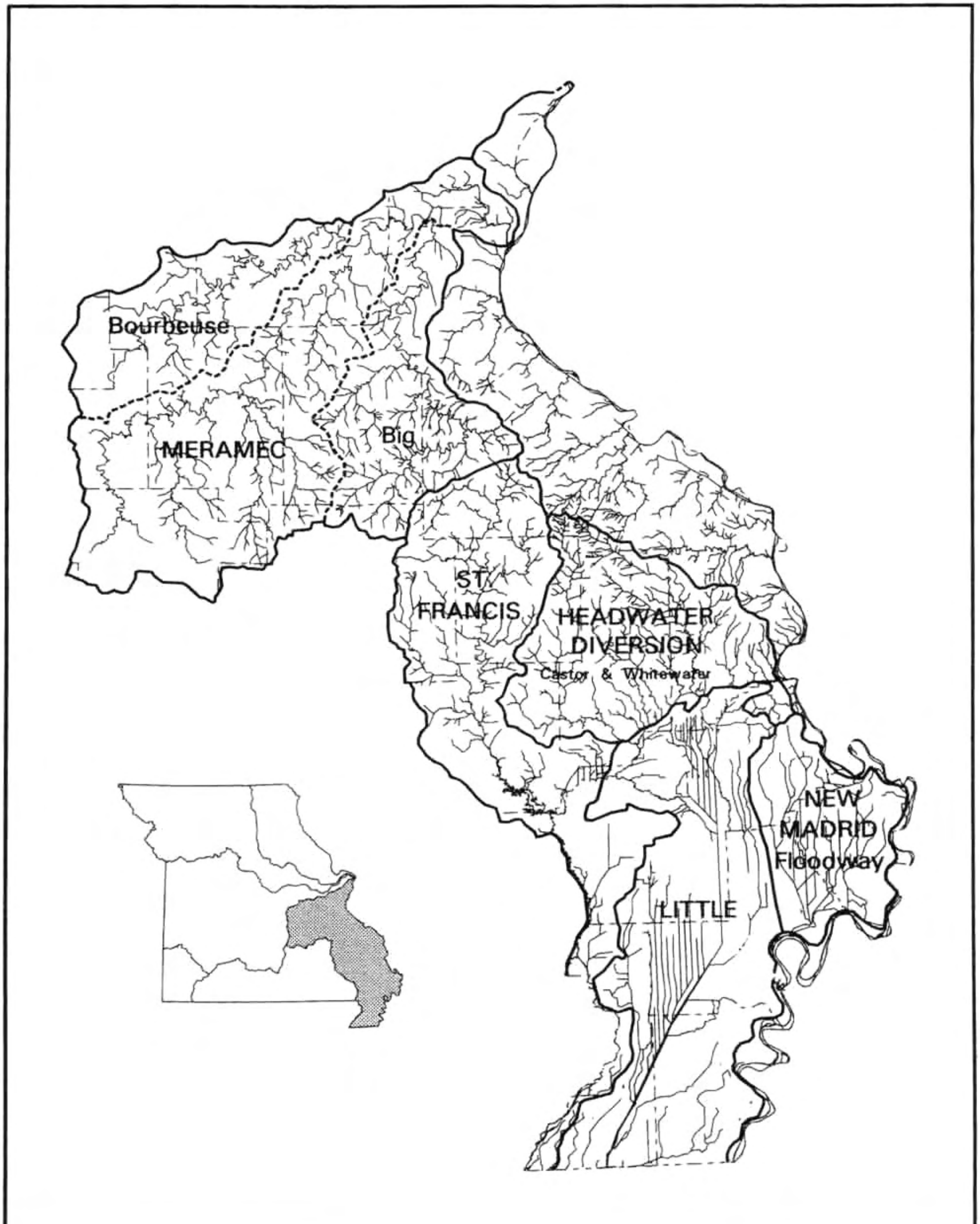

Figure 43. Lower Mississippi River tributaries in Missouri.

ward through the permeable surficial materials.

Much of the central and southern parts of the ***Meramec River*** basin are characterized by karst features such as sinkholes, losing streams, caves, and springs. Bedrock in most of the area is Cambrian- and Ordovician-age sedimentary rocks, primarily dolomite units. Solution activity in the dolomite has enlarged fractures and other openings, forming caves and groundwater conduits that facilitates rapid groundwater movement.

The oldest rock exposed in the Meramec basin is Precambrian-age igneous rock in the St. Francois Mountains. In Jefferson County, the ***Meramec River*** flows on rock as young as Mississippian-age. The uplands in the northern part of the basin, primarily in ***Bourbeuse River*** watershed, are underlain by Pennsylvanian-age sedimentary rocks.

Perennial flow in the ***Meramec River*** begins near the headwaters just east of *Salem* in Dent County. Upstream from here, the Meramec River is a losing stream and provides groundwater recharge. Downstream, flow of the stream is well-sustained, even during dry weather. The greatest change in flow characteristics occurs near *St. James* in Phelps County where flow from ***Maramec Spring*** enters the Meramec River.

Maramec Spring has an average discharge of about 145 ft^3/sec. In terms of discharge it is the largest spring in the ***Meramec River*** basin, and fifth largest spring in Missouri. Maximum recorded flow for the spring, which is occasionally inundated by backwater from the river, is 1,100 ft^3/sec. Discharge information was collected at the spring for 25 years during several periods between 1903 and 1981. The lowest recorded flow is 56 ft^3/sec, which occurred August 1, 1934. During low-flow periods, the Meramec River more than doubles its discharge with the addition of water from Maramec Spring.

Dry Fork enters the ***Meramec River*** a short distance downstream from Maramec Spring. Dry Fork drains an area of about 379 square miles. Upstream from the mouth of Dry Fork, the Meramec River drains a similar area (about 340 square miles).

Although the drainage areas are of similar size, the flow characteristics of ***Dry Fork*** and the upper ***Meramec River*** differ dramatically. In the upper and lower parts of its basin, Dry Fork is a perennial stream. However, in its middle reach, Dry Fork is a losing stream. Upstream from the losing reach, it drains about 313 square miles. Much of the surface flow entering this reach is channeled into the subsurface. The water resurfaces at ***Maramec Spring***. Additionally, there are several other major losing streams including ***Norman Creek*** and ***Asher Hollow*** that contribute groundwater recharge. Sinkholes and permeable surficial materials in the uplands further help provide recharge to Maramec Spring (Vandike, 1996).

The USGS operates three long-term gaging stations on the ***Meramec River***, and others on the ***Bourbeuse*** and ***Big rivers***. The Meramec River near Steelville drains about 781 square miles, which includes Dry Fork, the Meramec River above Dry Fork, and about 60 square miles between Dry Fork and Steelville. The average discharge here is 587 ft^3/sec, based on data collected between 1922 and 1993. The average annual runoff is 10.21 inches. Discharge of the river here exceeds 130 ft^3/sec 90 percent of the time, and 262 ft^3/sec 50 percent of the time.

Upstream from the gaging station near *Sullivan*, the ***Meramec River*** drains 1,475 square miles, and has an average discharge of 1,227 ft^3/sec. Average annual runoff here is 11.31 inches. Between *Steelville* and Sullivan, water from ***Huzzah Creek*** and ***Courtois Creek*** enters the Meramec. Both of these streams receive considerable groundwater from springs and seeps. In addition, there are numerous springs in this reach of the Meramec that contribute flow.

Between *Sullivan* and the lowest gaging station in the basin near *Eureka*, flow from the ***Bourbeuse*** and ***Big rivers*** enters the ***Meramec River***. The Bourbeuse River discharges into the Meramec near Union in Franklin County. It drains 818 square miles of the northern part of the Meramec River basin.

Pennsylvanian-age bedrock underlies much of the higher elevations of the

Bourbeuse watershed in Phelps, Crawford, Maries, Gasconade, and Franklin counties. Ancient sinkholes that formed prior to Pennsylvanian deposition in this area were subsequently filled with minerals including refractory clay, hematite, and pyrite. These filled sinkholes were developed in Ordovician age dolomites, and have been important mineral resources in the region.

Groundwater in the Pennsylvanian rock is typically more highly mineralized than water in the Ordovician rock beneath it. In some locations, water discharging from the Pennsylvanian rock increases the sulfate and total dissolved solids content of surface water, especially during periods of low flow.

Upstream from *Union*, the ***Bourbeuse River*** drains 808 square miles, and has an average discharge of 665 ft^3/sec. Data has been collected here since 1921. The water years of highest and lowest annual average flows on the Bourbeuse are 1993 and 1954, respectively, when discharges averaged 1,771 ft^3/sec and 106 ft^3/sec. Peak recorded discharge here occurred December 5, 1982, when flow reached 73,300 ft^3/sec. The lowest flow recorded here was 11 ft^3/sec on October 10, 1956. A comparison of the flow-duration curve characteristics of the upper ***Meramec River*** and the Bourbeuse River show how groundwater affects these streams. The Bourbeuse at Union drains 808 square miles, and has a runoff rate of 11.19 in./yr. Discharge exceeds 40 ft^3/sec 90 percent of the time, and 169 ft^3/sec 50 percent of the time. In comparison, the Meramec River near *Steelville* drains a smaller area, 781 square miles, and has a lower runoff rate, 10.21 inches. Yet, 90 percent of the time the flow at Steelville exceeds 130 ft^3/sec, and the river discharges more than 262 ft^3/sec 50 percent of the time.

The major difference between the two watersheds that affects the low-flow characteristics is the amount of groundwater that enters the rivers. There are numerous springs that discharge into the ***Meramec River***. While the ***Bourbeuse River*** does receive inflow from springs, they typically have much smaller discharges than the springs along the Meramec. Most of the uplands in the Bourbeuse watershed are underlain by Pennsylvanian-age sandstone and shale formations, or low-permeability Ordovician-age dolomites. Runoff rates are higher in the Bourbeuse basin, and groundwater recharge is less. Thus, more direct runoff is channelled into the river, and there is less water from groundwater sources to maintain flow during dry weather.

The ***Big River*** drains the eastern part of the ***Meramec River*** basin, and enters the Meramec about 2 miles upstream from *Eureka*. It drains about 912 square miles. Lead was mined extensively in the upper watershed in Washington and St. Francois counties from the 1700s until the middle 1900s There has also been considerable barite mining in the area during this century. Sediment eroded from tailings piles in these areas locally cause sediment loading and water-quality problems in the receiving streams.

Upstream from *Byrnesville*, the ***Big River*** drains 917 square miles. Average discharge here, based on data collected between 1921 and 1993, is 862 ft^3/sec. Average annual runoff here is 12.77 inches. In water year 1985, the highest-flow year on record, discharge averaged 1,934 ft^3/sec. Water year 1954 is the lowest-flow year on record when discharge averaged 227 ft^3/sec. Peak recorded flow here was measured September 25, 1993, when it reached 63,600 ft^3/sec. The lowest flow ever recorded, 25 ft^3/sec, was measured August 30, 1936. Low and medium flows here are higher than those of the ***Bourbeuse River***, but less than those of the ***Meramec River***. Discharge exceeds 116 ft^3/sec 90 percent of the time, and 337 ft^3/sec 50 percent of the time.

The ***Meramec River*** near *Eureka* drains an area of 3,788 square miles. Average discharge here for the years 1903-1906 and 1921-1993 is 3,187 ft^3/sec. Average annual runoff is 11.43 inches. Figure 44 shows average daily discharge for the Meramec River at Eureka during water years 1954 and 1985, the lowest and highest flow-years on record. In 1954, discharge averaged only 751 ft^3/sec, while in

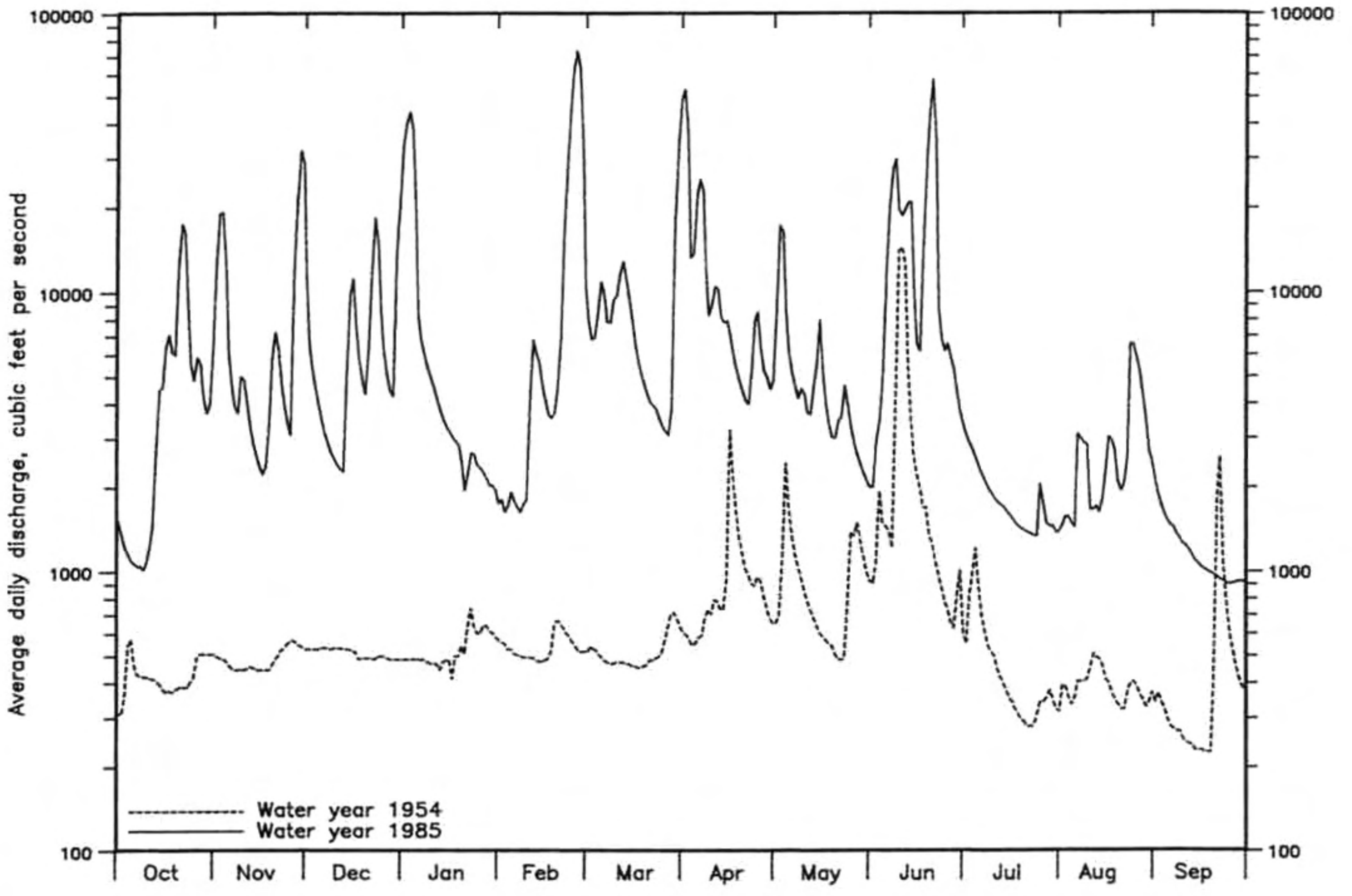

Figure 44. Average daily discharge of the Meramec River near Eureka, water years 1954 and 1985.

1985 it averaged 7,407 ft³/sec. Peak recorded flow here occurred December 6, 1982 at 145,000 ft³/sec. The lowest recorded flow is 196 ft³/sec, which was measured on August 27, 1936. Figure 45 is a flow-duration curve for the Meramec River at Eureka. As can be seen from the curve, the river has a high, well-sustained base flow. Discharge exceeds 520 ft³/sec 90 percent of the time, and 1,400 ft³/sec 50 percent of the time. Table 6 summarizes the flow and runoff characteristics for the Meramec River at different locations in the basin.

Surface water from the ***Meramec River*** basin is used for public water supply only in the lower part of the basin. Jefferson County PWSD #2 uses an intake in ***Big River*** to supply raw water. The City of *Kirkwood* pumps from the Meramec River, as does St. Louis County Water Company. St. Louis County has two intakes in the lower Meramec.

Mississippi River tributaries between the Meramec River and Cape Girardeau

Between the mouth of the ***Meramec River*** and the Headwater Diversion channel just south of *Cape Girardeau* are several creeks that drain directly into the ***Mississippi River***. These creeks typically drain less than 100 square miles. In the northern reach, their drainage basins are mostly underlain by Ordovician and older bedrock. Mississippian-age and younger rock underlies the upland areas along the Mississippi river near the mouths of the creeks. These drainages include ***Rock Creek*** and ***Joachim Creek***, both of which are in Jefferson County. Skelton (1966) calculated the 7-day Q_2 for Joachim Creek at *Hematite* to be 1.9 ft³/sec.

Plattin Creek drains parts of Jefferson, St. Francois, and Ste. Genevieve counties. Upstream from the town of *Plattin*, the creek

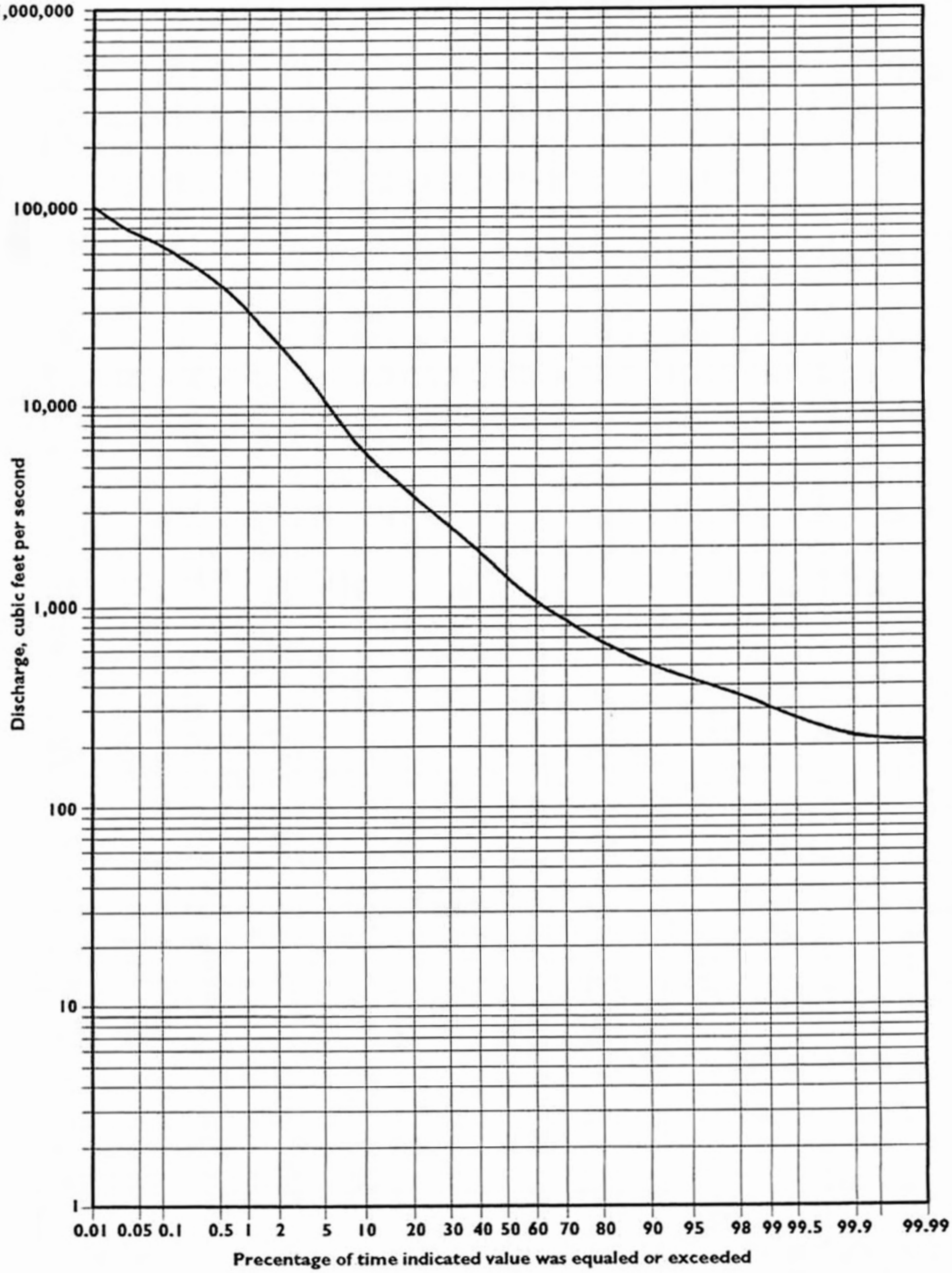

Figure 45. Flow-duration curve, Meramec River near Eureka, water years 1904-1993.

Station	Steelville	Sullivan	Eureka
Drainage area, mi^2	781	1,475	3,788
Drainage area increase between stations, mi^2, (%)		694 (88.9)	2,313 (156.8)
Average discharge, ft^3/sec	587	1,227	3,187
Average discharge increase between stations, ft^3/sec (%)		640 (109.0)	1,960 (159.7)
Runoff, inches	10.21	11.31	11.43
Runoff increase between stations, inches (%)		1.10 (10.8)	0.12 (1.06)
Highest average annual flow, ft^3/sec (year)	1,473 (1985)	3,014 (1985)	7,407 (1985)
Lowest average annual flow, ft^3/sec (year)	177 (1954)	341 (1954)	751 (1954)
Instantaneous peak discharge, ft^3/sec (date)	51,200 (6-18-85)	77,300 (6-9-45)	145,000 (12-6-82)
Instantaneous low flow, ft^3/sec (date)	74 (7-22-34)	131 (9-20-56)	196 (8-27-36)
Flow exceeded 90% of time, ft3/sec	130	270	520
Flow exceeded 50% of time, ft3/sec	262	588	1,400
Years of record	1922-1993	1921-1933, 1943-1993	1903-1906, 1921-1993
Major tributaries between stations		Courtois Creek Huzzah Creek Brazil Creek	Indian Creek Bourbeuse River Calvey Creek Big River

Data Source: Reed and others, 1993

Table 6. Long-term flow characteristics - Meramec River

drains 68.5 square miles. A gaging station operated here by the USGS between 1965 and 1992 showed Plattin Creek to have an average discharge of 44.7 ft^3/sec, and an average annual runoff of 9.23 inches. Maximum recorded flows were 9,000 ft^3/sec on June 22, 1969, and minimum recorded flow was 2.7 ft^3/sec on July 22, 1966.

Establishment Creek drains part of northeastern St. Francois County and northern Ste. Genevieve County. ***River Aux Vases*** drains the area south of Establishment Creek in central Ste. Genevieve County. There are large areas of sinkhole drainage in the uplands along the lower watershed of River Aux Vases south of Ste. Genevieve. The sinkholes and the cave systems that drain them are developed in Mississippian-age limestones.

Saline Creek drains an area of southern Ste. Genevieve and northern Perry counties. The City of *Perryville* has a surface-water intake in ***Saline Creek*** southwest of the city.

There is a band of intense karst development paralleling the ***Mississippi River*** through eastern Perry County. Thousands of sinkholes, more than 600 caves, and dozens of springs are located in this area. These karst features are developed mostly in middle Ordovician-age Joachim Dolomite and Plattin Formation. There are several sinkhole plains, some with more than 10 square miles of continuous sinkhole drainage, where all of the surface-water runoff is channelled underground.

Caves channel the water from the sinkholes to springs and karst resurgences along the streams bounding the sinkhole plains. ***Blue Spring Branch, Cinque Hommes Creek*** and ***Apple Creek*** receive water through this shallow karst drainage system. The springs discharging from the caves contribute little flow during dry periods, but after heavy rainfall their discharges will increase greatly until water entering the caves from the sinkhole plains is drained through the system.

Headwaters Diversion Channel

Nowhere else in Missouri does the topography and physiography change more abruptly that it does at the Ozark escarpment, the boundary between the Ozarks and the Southeastern Lowlands. The Southeastern Lowlands, also called the Mississippi Embayment and Bootheel, is a northern extension of the Coastal Plain. It extends from Cape Girardeau south to the Gulf of Mexico. The Southeastern Lowlands occupy an area of about 3,900 square miles.

The New Madrid Seismic Zone in the northern part of the Mississippi Embayment is the most active earthquake zone in the U.S. east of the Rocky Mountains, and is an area of geologic structural downwarping. Rock units cropping out in the uplands north of the Ozark escarpment dip into the subsurface in the Bootheel. In the central and southern parts of the Bootheel, rock units are several thousand feet below the surface of the landscape. This area is characterized by a history of faulting, earthquakes, buried rifts, and other major geologic occurrences that affected the surface of the Bootheel as well as the subsurface. Combined with this structural instability is the alluvial plain created by the meandering paths of the ancestral ***Mississippi, Ohio, St. Francis*** and ***Black rivers***. Erosion and deposition by these rivers have helped create the unique landscape of the Southeastern Lowlands. Over a period of thousands of years, these rivers have changed their paths numerous times, leaving thick deposits of alluvial sediments covering most of the Bootheel except for Crowleys Ridge and similar physiographic features paralleling the Ozark escarpment.

Crowleys Ridge, Hickory Ridge, and the Benton Hills are erosional remnants that escaped the total destruction of erosion. They are essentially islands of bedrock left in an alluvial plain. Rivers changing their paths cut new channels through low areas in the ridges, but left parts of the ridges standing in relief. This is an area that has had a long geologic history of major fault movements. Recent work indicates that faulting may have played a role in the formation of Crowleys Ridge and other similar bedrock outliers in the Southeastern Lowlands (Hoffman et al., 1994).

In addition to the more prominent positive topographic features, there are a few low sand ridges and terraces that historically have been relatively dry areas. Much of the Bootheel, though, was once characterized by poor surface drainage and swampland. Accounts of early settlers indicate that during the New Madrid earthquakes of 1811 and 1812, some areas settled several feet due to seismic activity (Beveridge, 1992).

The swampy nature of the Southeast Lowlands was caused by several factors. As described above, topographic relief in the area is very low, which hampers surface drainage. The Southeastern Lowlands have the highest average annual rainfall in Missouri, nearly 48 inches in places. Thus, in an average year there is an abundance of water from rainfall. Exacerbating the problem was the addition of water into the lowlands from the ***Castor, Whitewater, St. Francis*** and ***Black rivers***, which drained 3,750 square miles of the Ozarks Plateau and channelled it into the Southeast Lowlands. Add to all of this the water from the ***Mississippi*** and ***Ohio rivers*** which bound the eastern edge of the area, and the nature of the problem becomes abundantly clear. There is a tremendous volume of water draining through a nearly flat area. Groundwater further added to the problem. The alluvium covering most of the Bootheel is very permeable. The water table has a high elevation in most places, so even during dry weather groundwater flowing from the alluvium into the streams maintained high water levels in them.

Drainage projects, beginning in the late 1800s, improved surface drainage in the Bootheel, changing it from swamps to the most productive agricultural area in the state. An extensive area of the Bootheel is in the ***Little River*** watershed, which was characterized by river swamps. The ***Castor*** and ***Whitewater rivers***, which drain 1,190 square miles of the Ozarks north of the embayment, emptied into the lowlands, and flowed south through the Morehouse Lowlands into Arkansas. Flow from the Little River joined with them. To decrease inflow into the embayment, a new drainage channel called the ***Headwater Diversion Channel*** was constructed to divert the flows of the Castor and Whitewater rivers to the northeast into the ***Mississippi River*** just south of *Cape Girardeau*. This decreased drainage entering the Little River watershed by about 40 percent. Formerly ***St. Francis River*** tributaries, the Castor and Whitewater rivers are now Mississippi River tributaries.

The ***Castor River*** at *Zalma*, only a few miles upstream from the Headwater Diversion Channel, drains 423 square miles. Headwaters of the river are in southern Ste. Genevieve County. It also drains parts of Perry, Cape Girardeau, St. Francois, Madison, Wayne, and Bollinger counties.

A USGS gaging station gathered discharge data here from 1920 through 1991. Average annual flow during the period was 519 ft^3/sec. Annual runoff averaged 16.66 inches. The ***Whitewater River*** drains a similar size area to the east. Long-term flow measurements are not available for the Whitewater River. It drains parts of Perry, Bollinger, and Cape Girardeau counties.

St. Francis River

The ***St. Francis River*** has its headwaters in the St. Francois Mountains in Iron and Madison counties. The basin has the highest total relief of any in Missouri. Taum Sauk Mountain, highest point in Missouri, peaks at an elevation of 1772 ft msl and is on the west basin divide. The river forms the boundary with Arkansas on the eastern side of the Bootheel, and leaves Missouri at an elevation of about 235 ft msl. Total relief in the watershed is about 1,537 ft.

Although the rivers do not meet in Missouri, the ***Little River*** is a ***St. Francis River*** tributary because the flow of the two rivers combine a few miles south of the state border in northeastern Arkansas. Overall, the St. Francis River basin has decreased in size in the last century. Drainage from nearly 1,200 square miles was diverted through the Headwater Diversion Channel into the ***Mississippi River***, which substantially decreased the drainage area of the Little River. A series of nearly parallel drainage ditches were dug from the Headwater Diversion Channel into northern Arkansas in the Little River watershed to provide drainage. Similar drainage projects in the eastern part of the Bootheel drained water in the Charleston Lowland into the Mississippi River near *New Madrid*.

Flood-control reservoirs were constructed in the lower ***St. Francis River*** and ***Black River*** basins to control drainage from the Ozarks into the Southeast Lowlands. Levees were constructed along most of the streams including the ***Mississippi River***. Today, very little water flows into the Mississippi River from Missouri between the Headwater Diversion Channel and the southern tip of the state except near *New Madrid*, where drainage ditches channel water from the Charleston Lowlands into the river. The remaining water in the southeast lowlands is channelled into northern Arkansas.

The ***Little River*** formerly drained about 3,000 square miles, but diverting the flow of the ***Castor River*** and ***Whitewater River*** directly to the ***Mississippi River*** has decreased the drainage area to about 1,810 square miles. This is about 46 percent of the Southeast Lowlands, and includes parts of Bollinger, Cape Girardeau, Scott, Stoddard, New Madrid, Dunklin, and Pemiscott counties.

There is considerable published discharge information for several of the drainage ditches in this area. Flow of ***Little River Ditch*** *251* near *Kennett* was measured from 1926 through 1979. It drains an area of about 883 square miles, or nearly one-half of the ***Little River*** basin. Discharge here averaged 682 ft^3/sec through the period of record. Average annual runoff is about 10.5 inches. Maximum recorded discharge here is 8,380 ft^3/sec, which occurred November 20, 1957. Minimum recorded flow, which occurred September 23, 1969, is 22 ft^3/sec.

Besides draining a sizeable area in the Ozark Plateau, the main stem ***St. Francis River*** in Missouri also drains most of the Southeastern Lowlands west of Crowleys Ridge. Excluding the drainage contribution of the ***Little River***, the St. Francis drains about 1,700 mi^2 in Missouri. Of this, about 1,350 square miles, (77 percent), lies in the Ozark Plateau. The remaining 350 square miles is in the Southeast Lowlands. The St. Francis River drains parts of St. Francois, Ste. Genevieve, Iron, Madison, Wayne, Butler, Stoddard, and Dunklin counties.

The ***St. Francis River*** near *Patterson* drains 956 square miles, all of which is runoff from the St. Francois Mountains and the Ozark Plateau. Average discharge of the river here is 1,130 ft^3/sec, based on data collected between 1920 and 1993. Average annual runoff for this part of the watershed is 16.06 inches. Water year 1985 had the highest annual flow at 2,731 ft^3/sec. Water year 1941 had the lowest average discharge, 343 ft^3/sec. Peak recorded flow here is 155,000 ft^3/sec, which occurred December 3, 1982. The lowest recorded flow is 8.0 ft^3/sec, which was on August 28, 1936. Figure 46 is a flow-duration curve of the St. Francis River near Patterson. Discharge here exceeds 52 ft^3/sec 90 percent of the time, and 335 ft^3/sec 50 percent of the time.

Runoff entering the Southeastern Lowlands from the Ozark Plateau in the St. Francis River basin before 1940 worsened flooding in the Bootheel. To help alleviate this, the U.S. Army Corps of Engineers dammed the St. Francis River near the Ozark escarpment in 1941, and created ***Wappapello Lake***. About 1,310 square miles of drainage lies upstream of Wappapello Lake. At conservation pool level, it has a surface area of about 4,100 acres, and contains about 30,900 ac-ft of storage. At the top of the spillway, the reservoir has a surface area of 23,200 acres, and impounds 613,000 ac-ft of water. At maximum pool, which is uncontrolled above the spillway elevation, storage is 1,022,000 ac-ft. Besides flood control, the reservoir also supplies recreational benefits.

The average discharge of the ***St. Francis River*** below Wappapello is 1,567 ft^3/sec. Discharge here has been measured since 1940, and is completely controlled by releases from the lake. Average annual runoff is 16.24 inches. The highest average annual flow was in water year 1985 when it averaged 3,534 ft^3/sec. The driest year on record was water year 1941 when discharge averaged 406 ft^3/sec. Peak

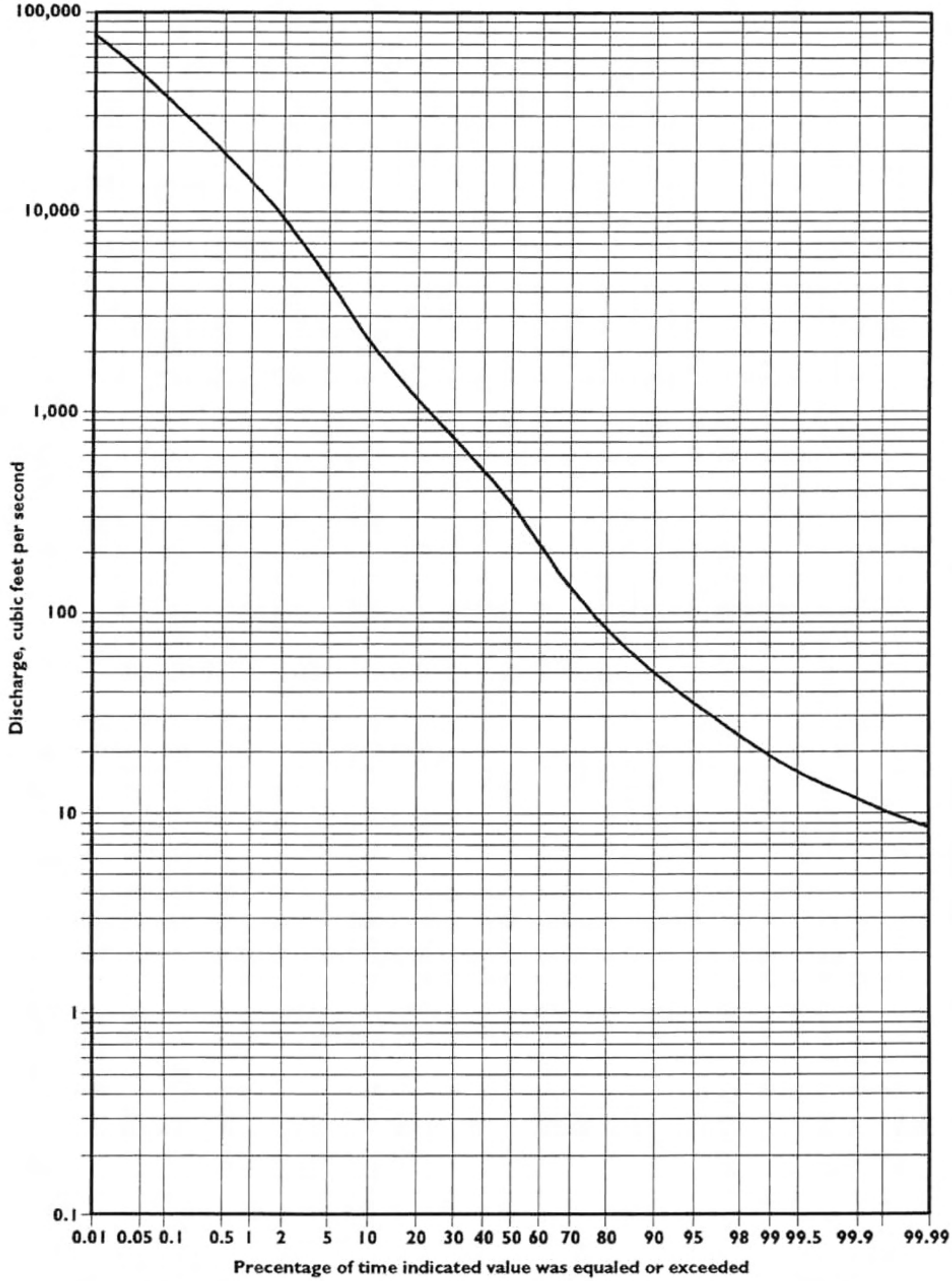

Figure 46. Flow-duration curve, St. Francis River near Patterson, water years 1922-1993.

discharge here occurred April 16, 1945, at 22,300 ft³/sec. Periods of no flow have been recorded at times during several years. Discharge here exceeds 40 ft³/sec 90 percent of the time, and 650 ft³/sec 50 percent of the time.

Figure 47 shows hydrographs of the ***St. Francis River*** at *Patterson* and below ***Wappapello Lake*** during water year 1985. Figure 48 shows the same two stations during water year 1941. To a great extent, the differences between the hydrographs of the two stations is the storage and later release of water from Wappapello Lake.

Two towns in the ***St. Francis River*** basin use surface water for water supply. The City of *Fredericktown* in Madison County uses a 158 acre lake plus water from the ***Little St. Francis River***. *Ironton* uses ***Shepherd Mountain Lake***, which has a surface area of 21 acres. Both of these towns are in areas where it is difficult to obtain large quantities of groundwater.

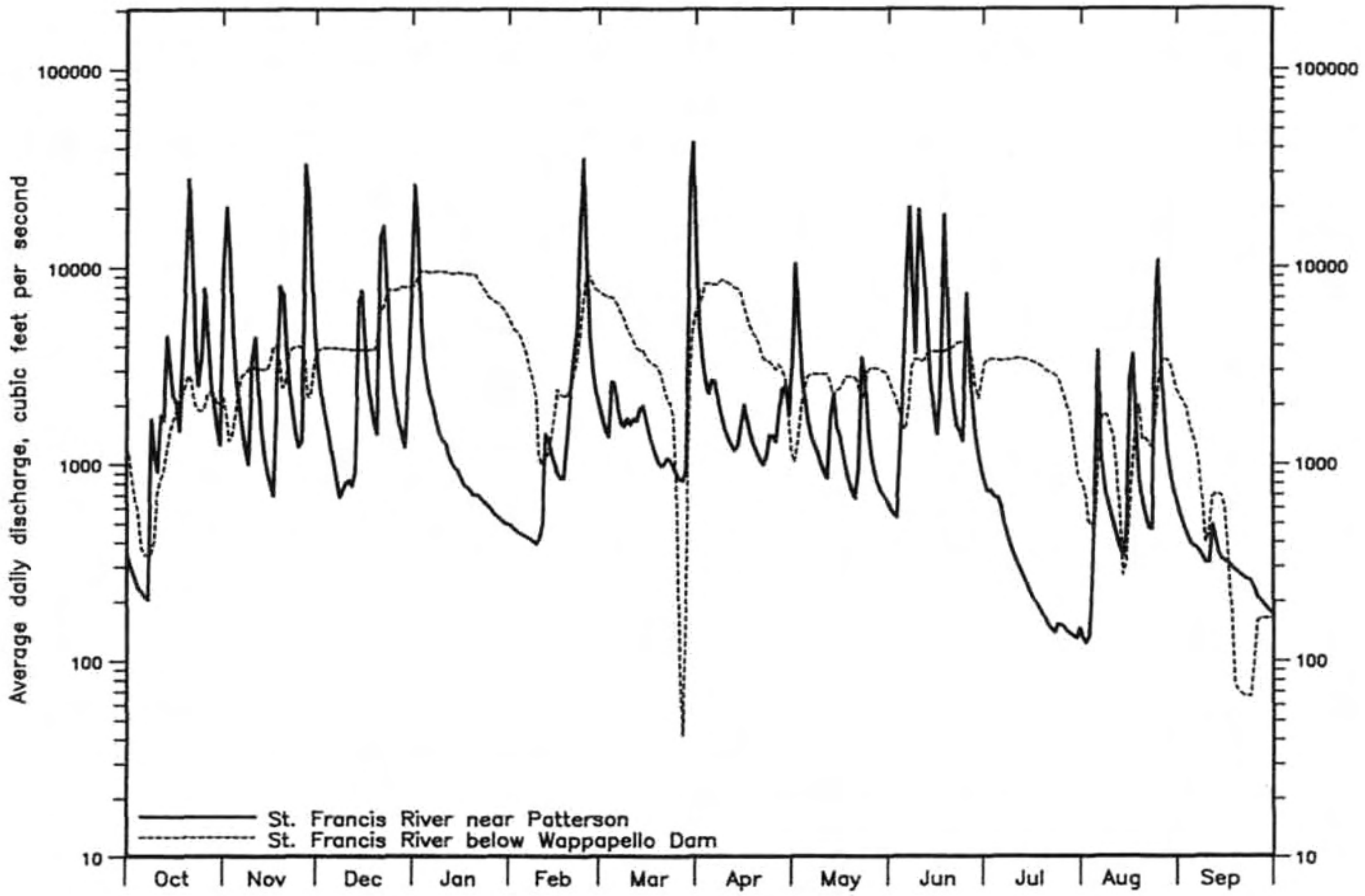

Figure 47. Average daily discharge of the St. Francis River near Patterson and below Wappapello dam, water year 1985.

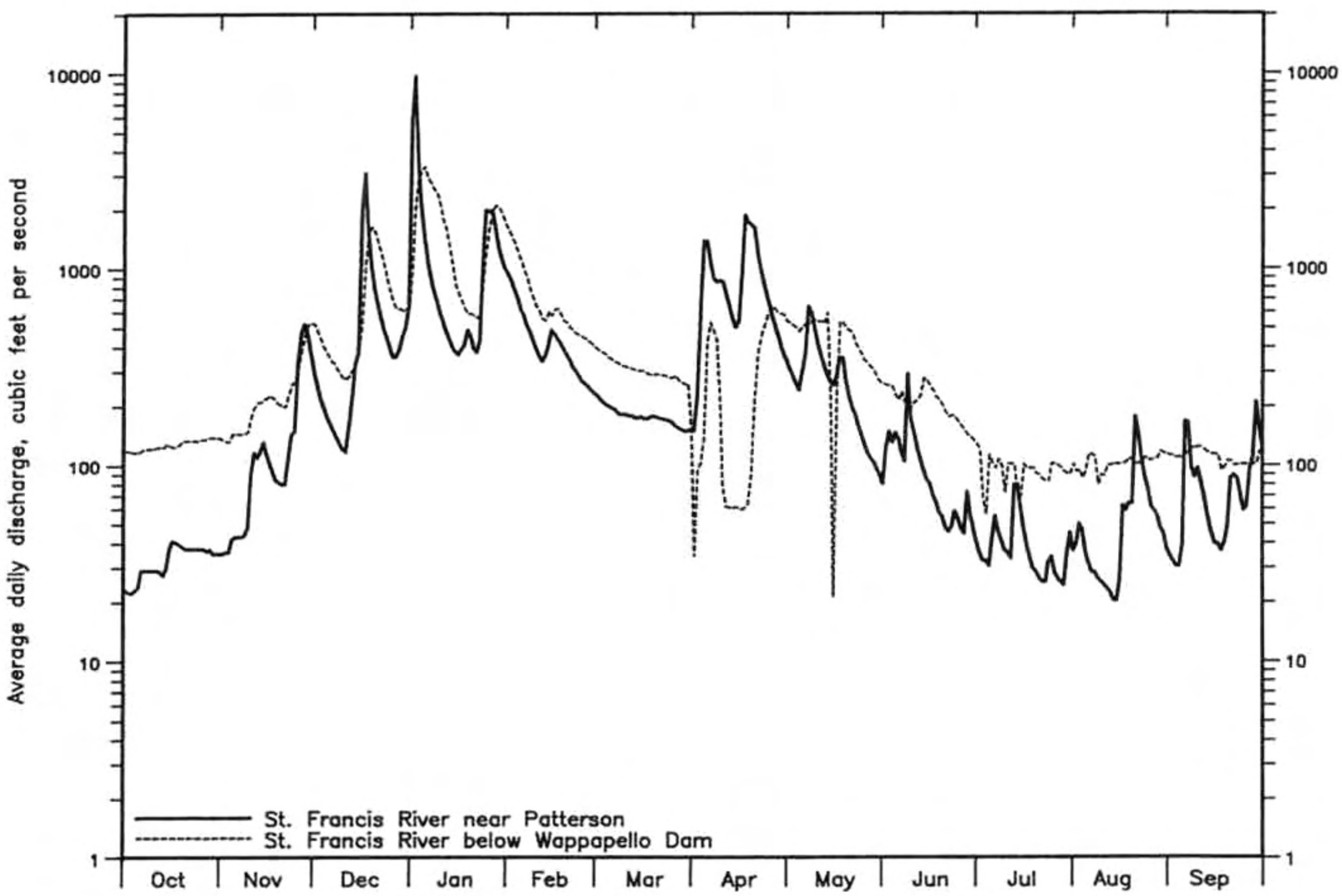

Figure 48. Average daily discharge of the St. Francis River near Patterson and below Wappapello dam, water year 1941.

Main Stem Lower Mississippi River

Between the mouth of the ***Missouri River*** and the southern tip of Missouri four miles south of Cottonwood Point in Pemiscot County, the ***Mississippi River*** meanders 320 miles to cover a straight-line distance of about 194 miles.

Discharge of the ***Mississippi River*** at *St. Louis* has been measured since 1861. Average daily flow here during the period of record is 186,100 ft³/sec. The river has a drainage area of about 697,000 square miles, and annual runoff averages 3.63 inches. Figure 49 shows discharge hydrographs for the Mississippi River at St. Louis for the years of lowest and highest discharge. Water year 1993 is the highest flow year on record. Discharge during the year averaged 429,700 ft³/sec, and peaked at 1,080,000 ft³/sec on August 1, 1993, a new peak discharge for the river here. Water year 1934 marked the year of lowest flow when discharge averaged 67,700 ft³/sec. The lowest flow ever measured on the river was 18,100 ft³/sec, which occurred December 23, 1863. Discharge of the river here exceeds 67,600 ft³/sec 90 percent of the time, and 148,000 ft³/sec 50 percent of the time.

At *Chester*, Illinois, the river has gained another 11,600 square miles of drainage, and drains a total of 708,600 square miles. More than one-third of the gain is from the ***Meramec River*** basin. Based on data collected from

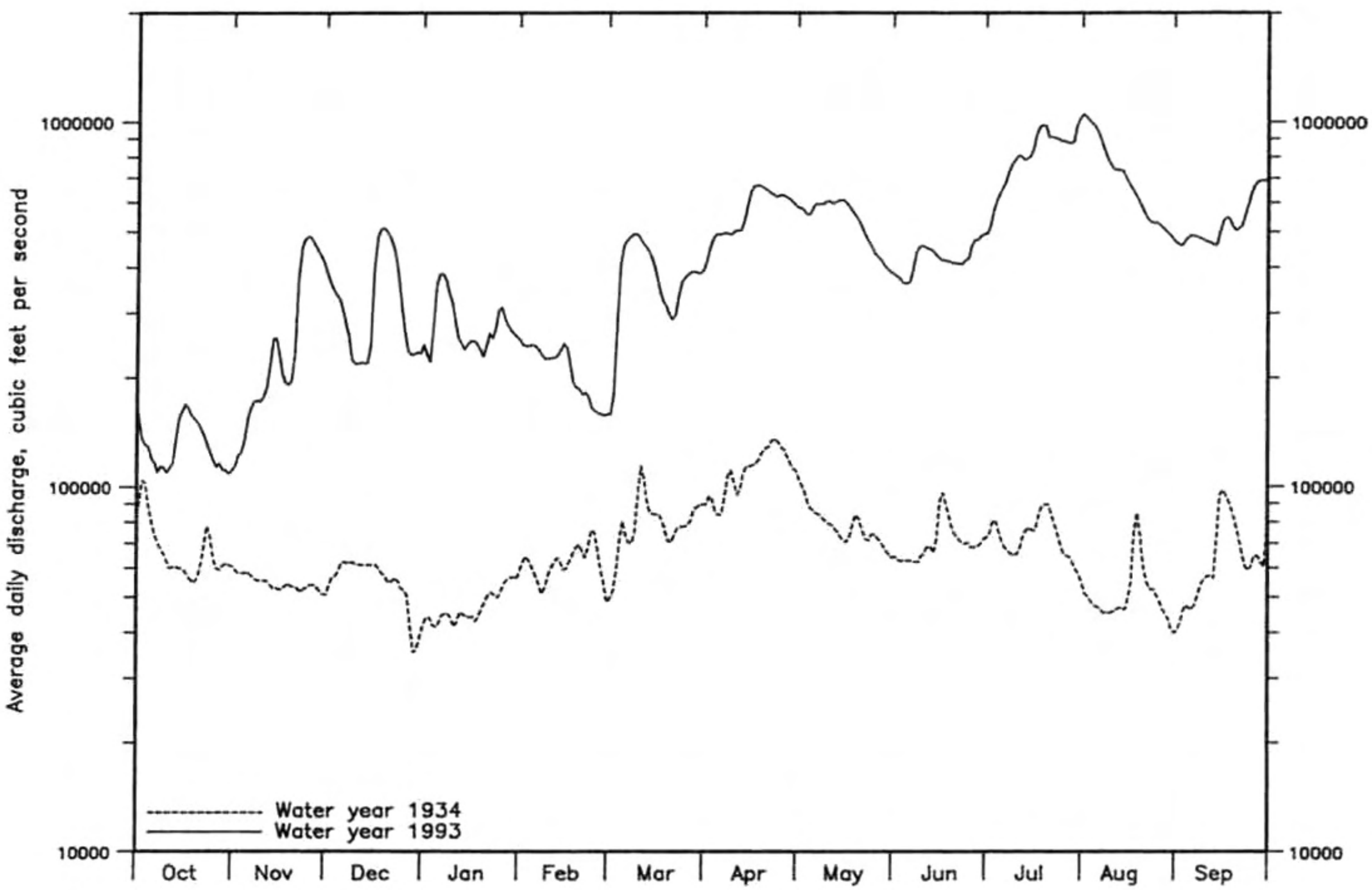

Figure 49. Average daily discharge of the Mississippi River at St. Louis, water years 1934 and 1993.

1927 to 1993, discharge averages 203,300 ft³/sec, and average annual runoff is 3.90 inches. Flow here exceeds 75,800 ft³/sec 90 percent of the time, and 163,000 ft³/sec 50 percent of the time (figure 50).

The ***Mississippi River*** at *Thebes*, Illinois, the southernmost gaging station on the Mississippi in or adjacent to Missouri, has a drainage area of 713,200 square miles, and an average discharge of 202,400 ft³/sec. This is based on data collected between 1932 and 1993. Runoff here averages 3.86 in./yr. Highest and lowest flow years on record here were water years 1993 and 1934, respectively, when discharge averaged 446,000 ft³/sec and 71,730 ft³/sec. Peak recorded discharge here was recorded August 7, 1993, at 996,000 ft³/sec. The minimum flow ever recorded here was 23,400 ft³/sec on December 13, 1937. Discharge here exceeds 73,000 ft³/sec 90 percent of the time, and 162,000 ft³/sec 50 percent of the time.

The ***Ohio River*** empties into the ***Mississippi River*** near *Charleston*. From here, the Mississippi flows another 126 miles south before reaching the southern border of the state near Cottonwood Point.

WHITE RIVER TRIBUTARIES

The ***White River*** and its tributaries drain about 10,645 square miles of southern Missouri, which is about 15.3 percent of the state (figure 51). The river has its headwaters in northwest-

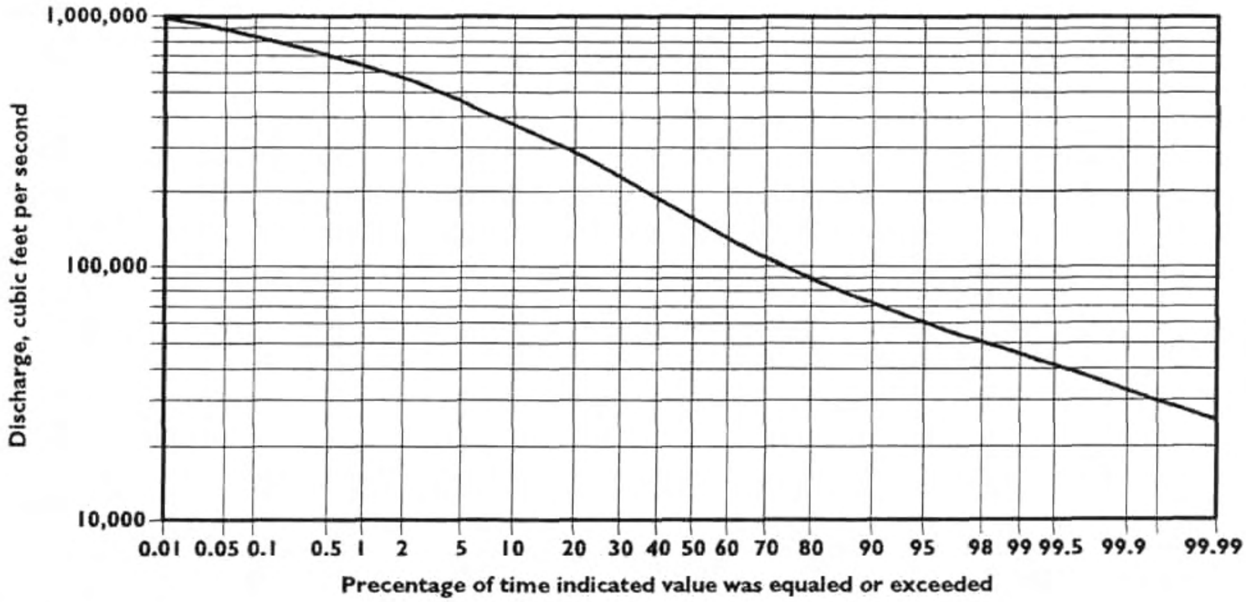

Figure 50. Flow-duration curve, Mississippi River at Chester, Illinois, water years 1934-1993.

ern Arkansas and flows northeast into Missouri in Barry County. It continues flowing east and north in Barry and Stone counties, then turns to the southeast and leaves Missouri in Taney County. Upstream from where the river leaves Missouri it drains 4,420 square miles. Essentially none of the White River in Missouri is a free-flowing stream. The river enters Missouri in the upstream reach of ***Table Rock Lake***. Below Table Rock it flows directly into ***Lake Taneycomo***, and the tailwaters of ***Bull Shoals Lake***, which lie mostly in Arkansas, reach nearly to Lake Taneycomo.

The upper ***White River*** basin in Missouri drains part of the Springfield Plateau, but most of the drainage basin is within the Salem Plateau. This part of the Ozarks is considered some of the most scenic country in the Mid-continent region. The area is rugged, characterized by rolling upland areas and steep, relatively narrow valleys hosting clear, spring-fed streams and rivers. Much of the area is forested, and natural water quality is generally excellent. During low-flow periods, the flows of rivers in this area are primarily derived from springs and seeps, thus water quality is to a great degree controlled by the quality of groundwater. The surface water is typically a calcium-magnesium-bicarbonate type, which reflects the dolomite bedrock from which the springs discharge. Sulfate, chloride, and nutrient levels are generally low except below wastewater discharges. Low dissolved oxygen levels below ***Table Rock*** and ***Bull Shoals*** dams typically occur during late summer and early fall months. The low levels are caused by organic materials depleting oxygen in the deeper parts of the reservoirs where there is little circulation. Large quantities of the low dissolved oxygen water are released through the turbines when electrical power is needed, affecting the dissolved oxygen content of the river for some distance downstream of the dams.

Powersite Dam, and ***Lake Taneycomo*** which it impounds, are the oldest of the ***White River*** dams and lakes. Constructed in 1912 by Empire District Electric Company, Powersite Dam was built to supply electrical power. Compared to other major reservoirs in the state it is quite small. At normal pool, the lake has a surface area of only about 2,100 acres, and impounds about 9,175 ac-ft.

Table Rock Lake, which is immediately upstream from Taneycomo, began filling in

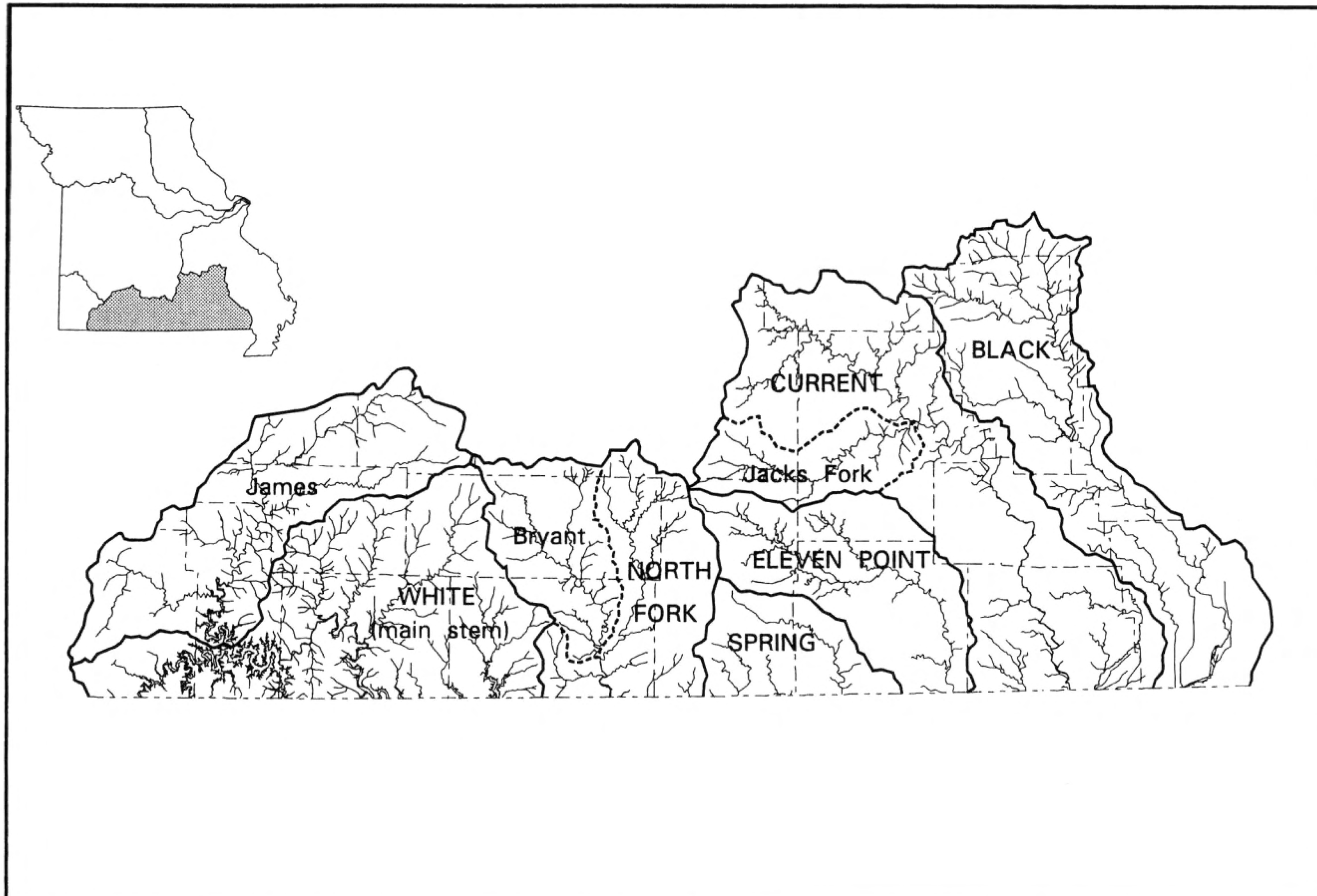

Figure 51. White River tributaries in Missouri.

1956 and was completed in 1959. Most of the lake lies in Missouri, and it drains an area containing 4,020 square miles, most of which is in northwestern Arkansas. At multipurpose pool level it has a surface area of 43,100 acres, and stores about 2,702,000 ac-ft of water. In addition, it has another 3,462,000 ac-ft of flood control storage (Atlas, 1986).

Only a small part of ***Bull Shoals Lake*** is in Missouri. Bull Shoals dam is near *Mountain Home* in northwestern Arkansas. The dam and reservoir were completed in 1952, and the lake is the largest of the ***White River*** impoundments. The multipurpose pool has a surface area of 45,440 acres, and contains 3,048,000 ac-ft of storage. The flood pool contains 5,408,000 ac-ft of flood-control storage (Atlas, 1986).

Discharge of the ***White River*** has been measured at a USGS gaging station near *Branson* since 1909. The site is about 600 ft downstream from Table Rock Dam; flow has been regulated by the dam since 1956. Average discharge here is 3,823 ft^3/sec, or an average annual runoff of 12.92 inches. Years of highest and lowest average discharge occurred in 1957 and 1954, respectively, when flows averaged 7,797 ft^3/sec and 729 ft^3/sec. Peak recorded discharge is 89,100 ft^3/sec, which occurred May 16, 1956. There are periods of no discharge when releases from Table Rock Dam are curtailed. Discharge here exceeds 2,250 ft^3/sec 50 percent of the time, and 140 ft^3/sec 90 percent of the time.

Although there is an abundance of surface water available from the ***White River*** and the lakes, only one city in Missouri - *Branson* - uses the White River for water supply. The City of Branson has a surface water intake in ***Lake Taneycomo***. Additionally, Branson uses eight deep wells that produce from the Ozark aquifer to meet water-supply needs.

James River

The ***White River*** has numerous tributaries in Missouri. The largest tributary which flows into the White River in Missouri is the ***James River***. The James River drains 1,460 square miles, including parts of Webster, Greene, Douglas, Christian, Lawrence, Barry, and Stone counties. The river flows into ***Table Rock Lake*** near *Kimberling City* in Stone County. Near *Springfield*, 1 mile downstream of the Blackman Water Treatment Plant intake, the river drains 246 square miles. Between 1955 and 1993, the discharge of the river here has averaged 237 ft^3/sec. Basin runoff has averaged 13.11 in./yr. Flows exceed 12 ft^3/sec 90 percent of the time, and 78 ft^3/sec 50 percent of the time.

The ***James River*** supplies part of the water supply for City of *Springfield*. Additionally, it receives treated wastewater from the same city. Water is removed from the James River near the Blackman Water Treatment Plant and is used for municipal water supply. A dam on the James River in southeastern Springfield impounds water for cooling a municipal steam-electric generating plant. Treated wastewater is discharged into ***Wilson Creek*** in the southwestern part of Springfield. Wilson Creek is a James River tributary. Part of the treated wastewater disappears into the subsurface a short distance downstream from the treatment plant, and it resurfaces at ***Rader Spring***, a short distance downstream on Wilson Creek. Water in the James River is a calcium-bicarbonate type, reflecting the limestone bedrock in the Springfield Plateau. Below its confluence with Wilson Creek the water contains elevated bacteria and nutrients (Reed and others, 1993).

Upstream from *Galena*, the ***James River*** drains 987 square miles, and has an average annual runoff of 13.56 inches, based on data collected between 1921 and 1993. The highest flow recorded here occurred September 25, 1993, when discharge measured 73,200 ft^3/sec. The water year with the highest average discharge was 1927, when it averaged 2,499 ft^3/sec. The water year with the lowest average flow and the lowest recorded flow was 1954, when discharge averaged 119 ft^3/sec and reached a low of 10 ft^3/sec on September 20. Discharge here exceeds 430 ft^3/sec 50 percent of the time, and 90 percent of the time flow is greater than 118 ft^3/sec.

Other White River tributaries in Missouri include Bull Creek, Swan Creek, Beaver Creek, Big Creek, and the Little North Fork River. These creeks drain into the White River at Taneycomo and Bull Shoal lakes.

North Fork River

The ***North Fork River*** and its main tributary, ***Bryant Creek***, drain parts of Wright, Texas, Howell, Douglas, and Ozark counties. The North Fork rises near *Mountain Grove*, and the river drains 1,310 square miles of the Salem Plateau. It flows into ***Norfork Lake*** near *Tecumseh*, a few miles north of the Arkansas border.

Upstream from *Tecumseh*, ***Bryant Creek*** and the ***North Fork River*** are as close to being identical basins as can be found in Missouri. Their drainage areas, geology, physiography, and climate are very similar. The North Fork drains 561 square miles, while Bryant Creek drainage is slightly larger at 570 square miles. Both basins are underlain by Ordovician dolomites and sandstones. Jefferson City and Cotter dolomites underlie the upper watersheds. The Roubidoux Formation, an interbedded sandstone and dolomite, forms the valley walls on Bryant Creek and the North Fork, and the bed of many tributary valleys of both watersheds. The Gasconade Dolomite forms the lower valley walls and river bed along both streams. Despite these similarities, the discharge characteristics of these otherwise nearly identical streams vary considerably.

Between 1945 and 1985, the ***North Fork River*** had an average discharge of 730 ft^3/sec. Despite its slightly larger drainage area, discharge for ***Bryant Creek*** averaged only 530 ft^3/sec, 200 ft^3/sec less than the North Fork. The North Fork River had an average annual runoff of 17.67 inches, while that for Bryant Creek was 12.62 inches. Annual runoff for this region averages about 14 inches. The reason for the difference in discharge between the two streams is simply hydrologic thievery - water is being pirated from Bryant Creek and transported through the subsurface to the North Fork River.

Like most of the ***White River*** tributaries, there are numerous springs along both ***Bryant Creek*** and the ***North Fork River***. The North Fork River has the largest springs, including ***Double Spring*** with an average discharge of about 127 ft^3/sec, and ***North Fork Spring***, which discharges an average of about 70 ft^3/sec (Vineyard and Feder, 1974). These two springs are less than 1,000 ft apart.

The largest spring in the ***Bryant Creek*** basin is ***Hodgson Mill Spring***, which has an average discharge of about 35 ft^3/sec. Hodgson Mill Spring is about 4.5 miles west of ***Double Spring*** and ***North Fork Spring***. Dye tracing has shown that these three springs are separate outlets of a single spring system. Fluorescent dyes injected into losing streams in upper Bryant Creek, and adjacent drainage in the upper ***Gasconade River*** basin more than 30 miles to the northwest, reappear at Double, North Fork and Hodgson Mill springs (Williams, 1986 and 1987, and Brown, 1988).

The quality of water issuing from these springs is essentially identical, further indicating that the springs are separate rises from the same subsurface drainage system. However, most of the recharge area of these three springs, whose combined discharge averages about 230 ft^3/sec, is in the upper ***Gasconade River*** and upper ***Bryant Creek*** basins, yet most of the water discharges into the ***North Fork River***, which serves to increase its average discharge while decreasing that of Bryant Creek.

Figure 52 is a hydrograph showing discharge of ***Bryant Creek*** and the ***North Fork River*** in water year 1981, which was a relatively dry year. Much of the year, flow in both streams was primarily groundwater inflow. The difference in discharge between the two streams was generally 150 ft^3/sec to 200 ft^3/sec, which is approximately the flow of Double and North Fork springs.

Between 1944 and 1993, the ***North Fork River*** near *Tecumseh* had an average discharge of 743 ft^3/sec, and a runoff or 18.00 in./yr. Figure 53 shows hydrographs of the stream for the highest and lowest water years on record. In water year 1985, discharge averaged 1,555 ft^3/sec, while in 1954 the average flow was

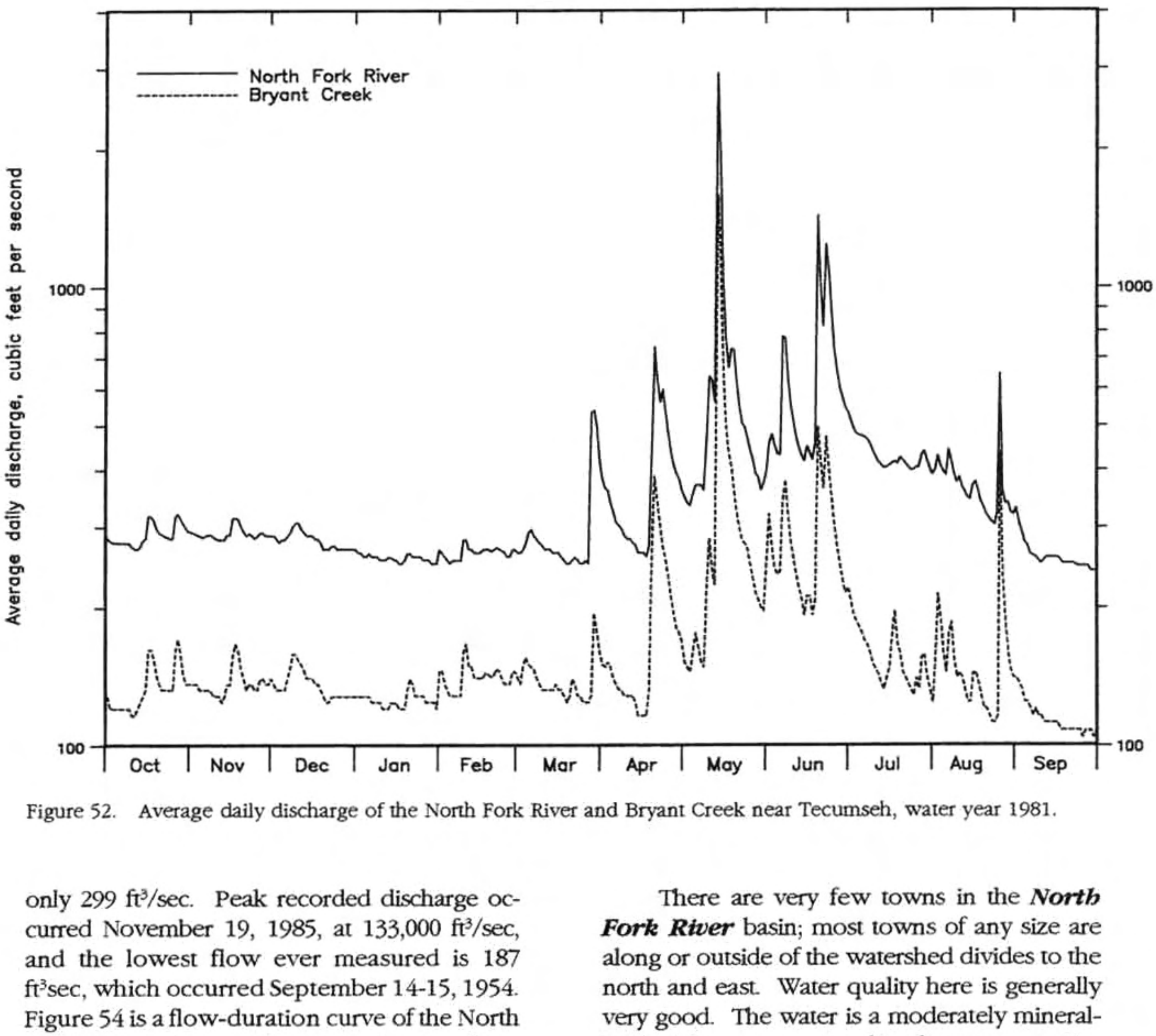

Figure 52. Average daily discharge of the North Fork River and Bryant Creek near Tecumseh, water year 1981.

only 299 ft³/sec. Peak recorded discharge occurred November 19, 1985, at 133,000 ft³/sec, and the lowest flow ever measured is 187 ft³sec, which occurred September 14-15, 1954. Figure 54 is a flow-duration curve of the North Fork River at Tecumseh. As can be seen from the graph, the North Fork has a very high, well-sustained base flow provided by numerous large springs. Discharge exceeds 288 ft³/sec 90 percent of the time, and 501 ft³/sec 50 percent of the time.

The ***North Fork River*** drains into ***Norfork Lake*** a few miles north of the Arkansas state line. Most of the 22,000 acre lake is in Arkansas. It contains 1,251,000 ac-ft of storage in the multipurpose pool, and an additional 1,983,000 ac-ft of flood control storage. Its benefits include flood control, recreation, and hydroelectric power (Atlas, 1986).

There are very few towns in the ***North Fork River*** basin; most towns of any size are along or outside of the watershed divides to the north and east. Water quality here is generally very good. The water is a moderately mineralized calcium-magnesium-bicarbonate type. Nutrients, sulfate, and chloride are generally low. No towns in the North Fork River basin use surface water for municipal water supply.

Black River

The ***Black River*** is a major ***White River*** tributary. It drains about 1,400 square miles in Missouri, but the flows of the ***Current River, Eleven Point River***, and ***Warm Fork of the Spring River*** are added to it in northeastern Arkansas. The Black River rises in Iron County, and it drains the western side of the St. Francois Mountains; Taum Sauk Mountain is on the east

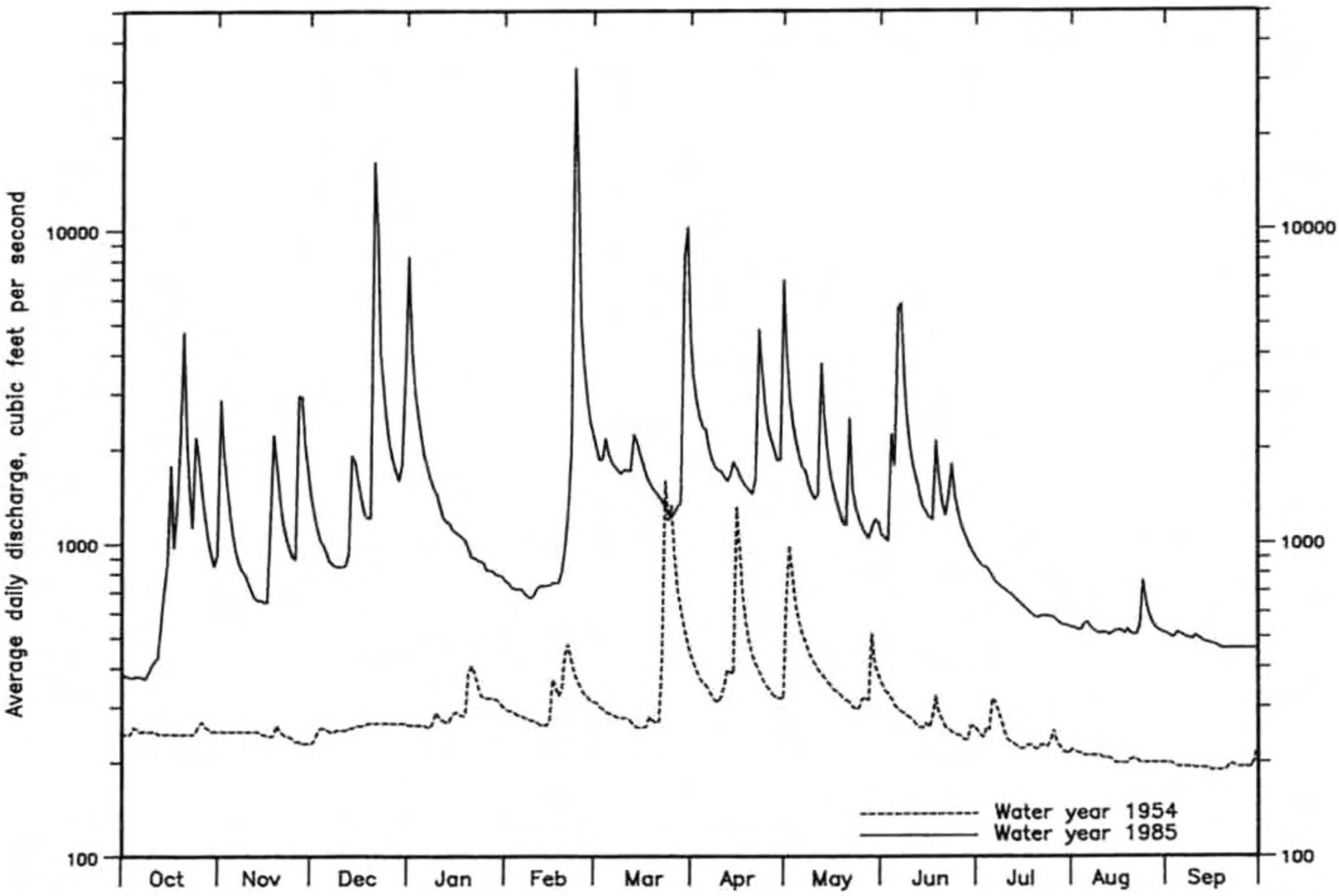

Figure 53. Average daily discharge of the North Fork River near Tecumseh, water years 1954 and 1985.

drainage divide. The river drains all or parts of Iron, Dent, Reynolds, Wayne, Shannon, Carter, Ripley, and Butler counties.

The watershed is about 90 miles long in Missouri, and generally 20 miles to 30 miles wide. Precambrian igneous rock crops out in the northeastern part of the basin. Narrow valleys that cut into the resistant igneous rock forms shut-ins at several places in the upper watershed. Cambrian sedimentary rock forms the bedrock surface throughout much of the upper part of the watershed, and Ordovician rock underlies the lower basin. Most of the active underground lead mines in Missouri are in the ***Black River*** basin. Clearwater Dam impounds the Black River near Piedmont. Flows are regulated below the dam to decrease flooding in the Bootheel. The Black flows into the Southeastern Lowlands near Poplar Bluff.

Near *Annapolis*, upstream from ***Clearwater Lake***, the ***Black River*** drains 484 square miles. Based on data collected between 1939 and 1993, discharge here averages 591 ft^3/sec, and runoff averages 16.60 in./yr. Discharge in water year 1985, highest flow year on record, averaged 1,420 ft^3/sec, while discharge in water year 1954, lowest on record, was 244 ft^3/sec. Highest and lowest instantaneous discharges were 98,500 ft^3/sec on November 19, 1985, and 67 ft^3/sec on August 12, 1965. Figure 55 is a flow-duration curve for the Black River near Annapolis. Discharge here exceeds 116 ft^3/sec 90 percent of the time, and is greater than 271 ft^3/sec 50 percent of the time.

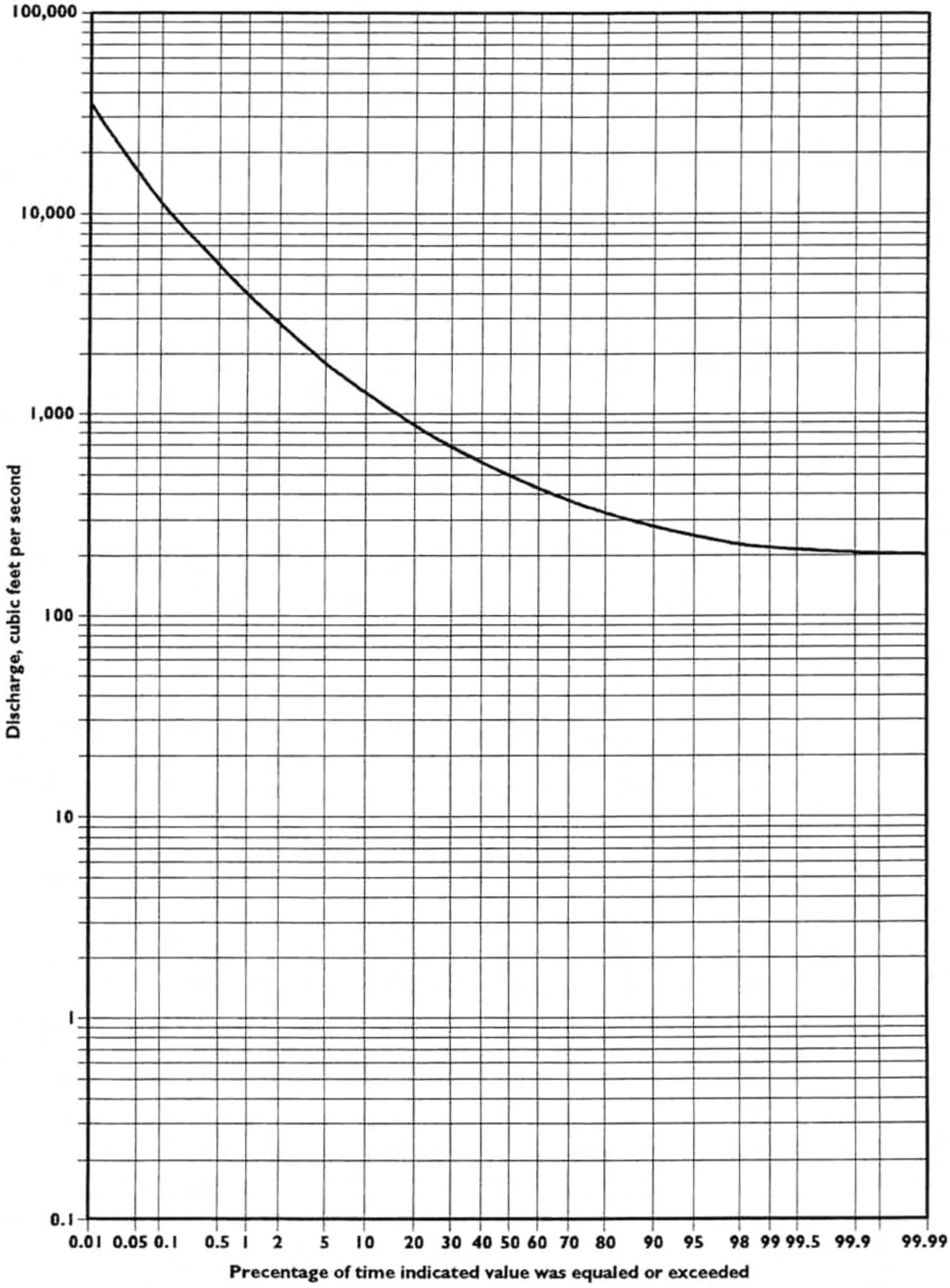

Figure 54. Flow-duration curve, North Fork River near Tecumseh, water years 1945-1993.

There is a hydroelectric facility in the ***East Fork Black River*** drainage that takes advantage of the high relief in this area as well as electrical demand patterns. Taum Sauk Hydroelectric Plant is a Union Electric facility. It consists of a lower reservoir on the East Fork Black River, an upper reservoir on top of Proffit Mountain, and a hydroelectric plant between them. During peak electrical demand periods, water is released from the upper reservoir into a 6,500 ft-long tunnel leading to the turbines and generators at the upper end of the lower reservoir. The vertical drop between the two is nearly 800 feet. Water is pumped back into the upper reservoir during low electrical demand periods when there is excess power available.

Like most areas in the Ozarks, losing streams and other karst features have developed in the Black River basin. One of the most notable losing streams is ***Logan Creek***, which drains part of western Reynolds County. Logan Creek is perennial and a gaining stream in the upper watershed, but there is a several-mile dry reach upstream of *Ellington* where surface water disappears through the permeable streambed into bedrock conduits below. Instead of reappearing at a spring farther downstream in the watershed, the flow lost here crosses the basin divide and reappears at ***Blue Spring***, about 10 miles to the southwest near *Owls Bend* on the ***Current River*** (Vineyard and Feder, 1974).

Clearwater Dam is on the ***Black River*** near *Piedmont*. The dam is in Wayne County, but nearly all of the reservoir is in Reynolds County. Upstream from the dam, the Black River drains 898 square miles. The reservoir was constructed primarily for flood control and began filling in 1948. Along with flood control, it is a popular recreational area. The permanent pool is relatively small. It has a surface area of about 1,600 acres and contains only about 21,920 ac-ft of storage. The remaining storage, 391,800 ac-ft, is flood storage.

The ***Black River*** flows into the Southeastern Lowlands at *Poplar Bluff*. Here, the river drains 1,245 square miles and has an average discharge of about 1,330 ft^3/sec. This is based on flow data collected between the periods 1936-1937 and 1939-1993. Average annual runoff is 14.51 inches. Water year 1984 was the year of highest flow and discharge averaged 2,858 ft^3/sec. Water year 1954 was the lowest, and flow averaged 564 ft^3/sec. Maximum flow recorded here was 65,000 ft^3/sec on December 4, 1982, minimum recorded flow was 180 ft^3/sec on September 25-26, 1966. Flow of the river here exceeds 369 ft^3/sec 90 percent of the time, and 781 ft^3/sec 50 percent of the time. The cities of Poplar Bluff and Piedmont have intakes in the Black River and use it for municipal water supply.

Current River

For those who are familiar with it, the ***Current River*** is synonymous with canoeing and river recreation in Missouri. The river flows 140 miles through the Salem Plateau. The area is characterized by swift, clear streams and numerous large springs, which provide high base flows even during dry weather. In all, the Current drains about 2,120 square miles in Missouri in Dent, Texas, Shannon, Howell, Carter, Reynolds, Oregon, Butler, and Ripley counties. The Current River from *Montauk* to near *Doniphan* is within the Ozark National Scenic Riverway, and is under the management of the National Park Service.

The ***Current River*** begins in Dent County where ***Montauk Spring***, eleventh largest spring in Missouri, rises from openings in the Ordovician-age Gasconade Dolomite. The spring discharges an average of about 60 ft^3/sec, and much of the time provides essentially all of the water in the Current River here. Upstream from *Montauk*, the Current River is called ***Pigeon Creek*** and is mostly a losing-stream watershed. Only during wet weather does Pigeon Creek carry appreciable water in the lower reaches. Water disappearing into the subsurface in Pigeon Creek provides recharge to Montauk Spring.

The ***Current River Basin*** contains more large springs than any other Missouri watershed. Of the nine springs in Missouri with average discharges greater than 100 ft^3/sec, four of them

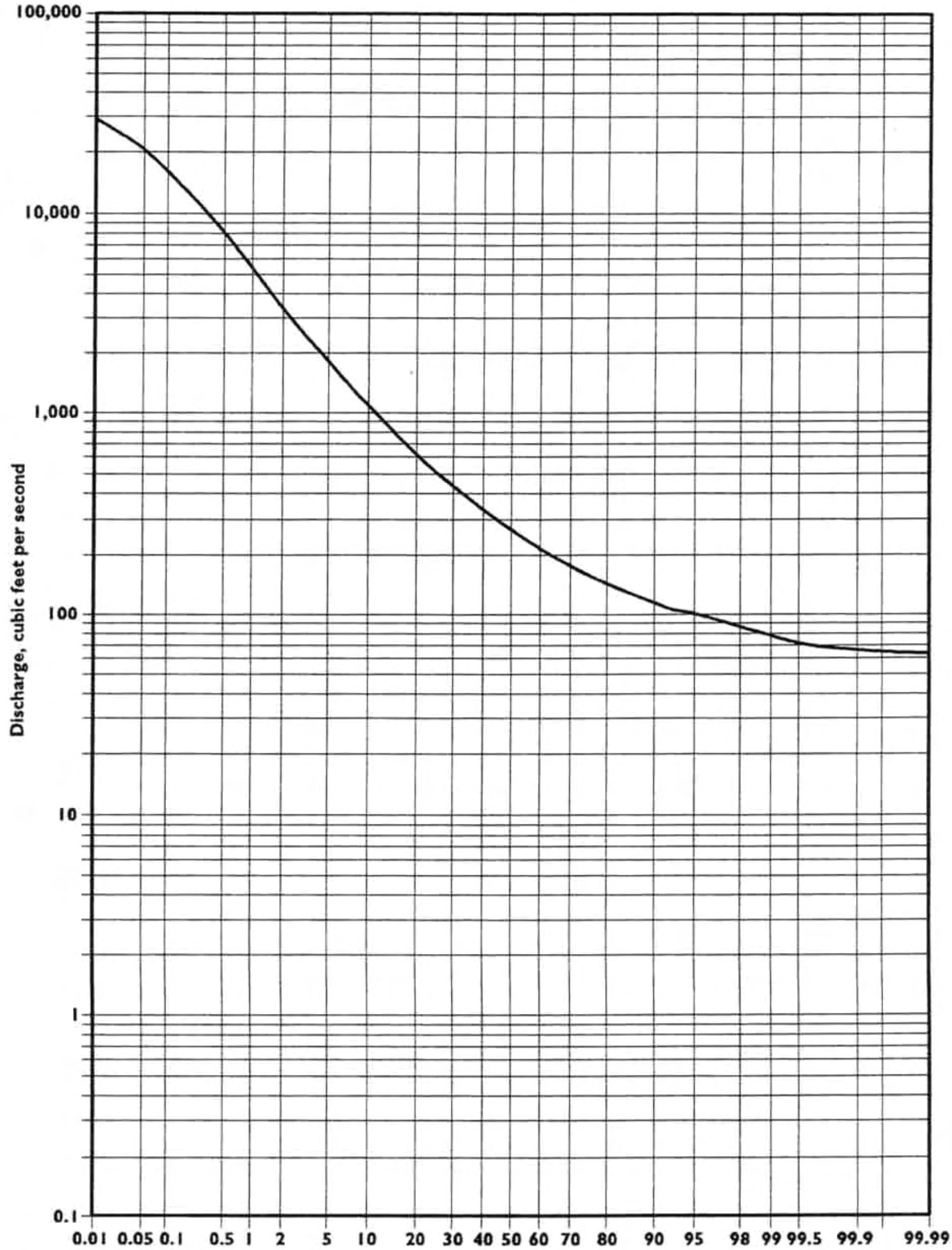

Figure 55. Flow-duration curve, Black River near Annapolis, water years 1940-1993.

are along the Current River. Seven are in the ***White River*** basin. The high concentration of large springs provides a high base flow for the Current River. Discharge of the river tends to increase modestly between springs, and substantially where major springs discharge into the river. ***Welch Spring, Cave Spring, Pulltite Spring***, and ***Round Spring*** add their flows into the upper Current River. In addition, there are areas below Pulltite and Round springs where considerable water discharges directly into the river through its bed (Aley, 1978). The main tributary of the Current River is the ***Jacks Fork***.

The ***Jacks Fork*** has a relatively small drainage area of only 422 square miles. However, it has a very high average discharge due to springs along its reach. ***Alley Spring***, Missouri's seventh largest spring, with an average discharge of about 125 ft³/sec, discharges into the Jacks Fork a few miles upstream from Eminence. At Eminence, the Jacks Fork drains 398 square miles. The discharge of the Jacks Fork here averages 457 ft³/sec, and average annual runoff is 15.60 inches.

Figure 56 shows the average daily flow for the ***Jacks Fork*** at *Eminence* during water year 1985 and water year 1954, the years of the highest and lowest average annual flows. Discharge averaged 1,072 ft³/sec in water year 1985, but only 154 ft³/sec in water year 1954. Despite the relatively small drainage, the lowest flow measured here during the period of record, 1921-1993, was 64 ft³/sec. Discharge exceeds 123 ft³/sec 90 percent of the time, and 241 ft³/sec 50 percent of the time.

Blue Spring adds its discharge to the ***Current*** near *Owls Bend*. Average flow of Blue Spring is about 107 ft³/sec, much of which comes from outside of the Current River basin. Water lost into the subsurface on

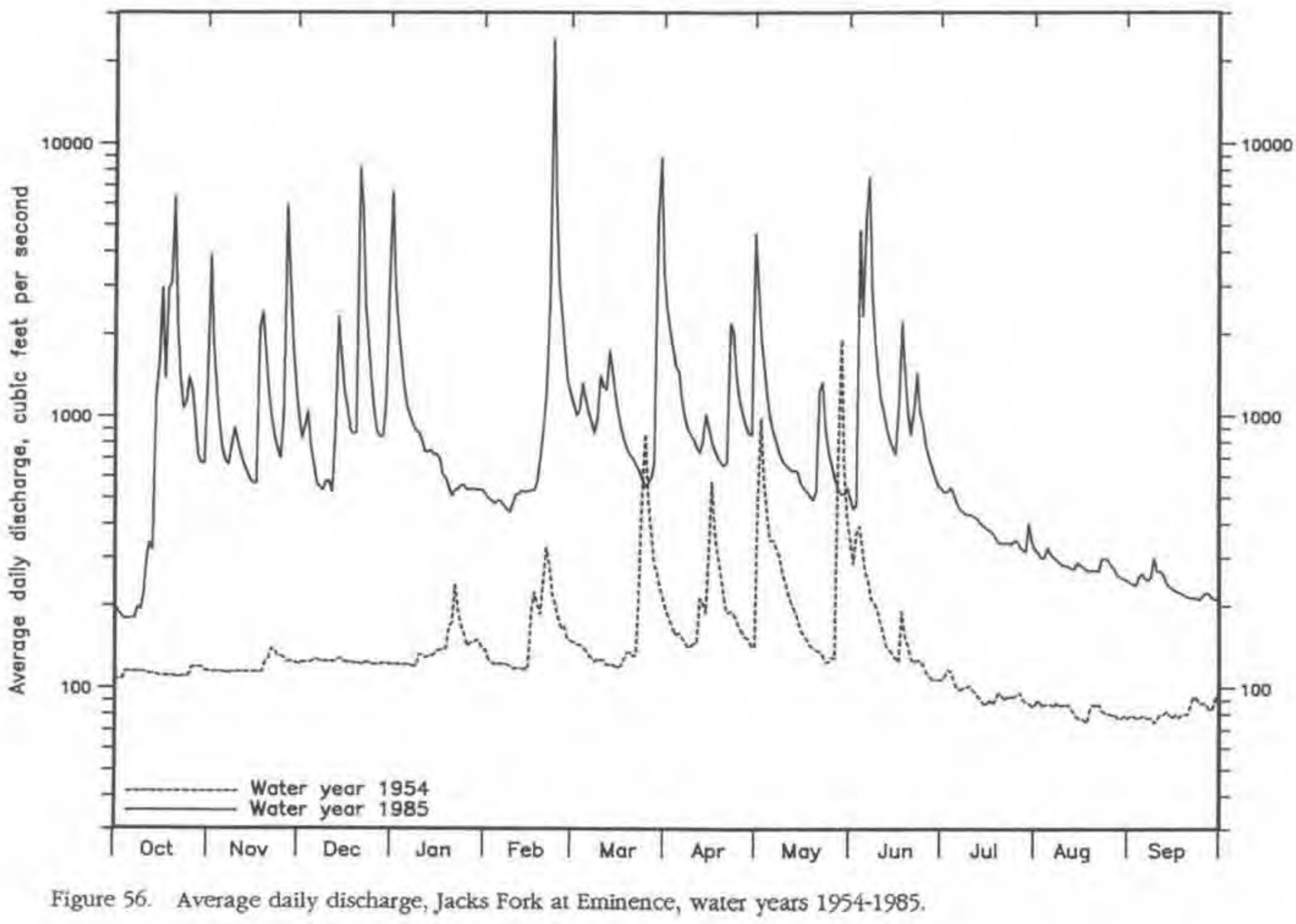

Figure 56. Average daily discharge, Jacks Fork at Eminence, water years 1954-1985.

Logan Creek, a ***Black River*** tributary, reappears at Blue Spring.

At *Van Buren*, the ***Current River*** drains 1,662 square miles. Flow here between 1912 and 1993 averaged 1,965 ft^3/sec, and annual runoff has averaged 16.02 inches. Water year 1985 had the highest average flow, 4,811 ft^3/sec, while water year 1956 was the lowest with an average discharge of 799 ft^3/sec. Maximum recorded flow here was 125,000 ft^3/sec on August 21, 1915, and minimum recorded flow was 473 ft^3/sec, which was recorded October 7, 1956. About one-half of the time flow is greater than 1,230 ft^3/sec, and 90 percent of the time discharge exceeds 691 ft^3/sec.

The largest spring in Missouri enters the ***Current River*** about 4 miles downstream from *Van Buren*. Appropriately named, ***Big Spring*** discharges an average of about 443 ft^3/sec into a spring branch leading to the Current River. At normal flow, Big Spring discharges enough water to meet the average water supply needs of Missouri's three largest cities. The City of *St. Louis* uses an average of 152 mgd, *Kansas City*'s average use is 85 mgd, and *Springfield* uses an average of about 23 mgd (DEQ, 1991). Combined water use for these three cities averages 260 mgd. Average discharge of Big Spring is about 286 mgd.

Peak discharge of the spring has been estimated at 2,000 ft^3/sec. However, high spring stages tend to occur during floods on the ***Current River***, and backwater from the river makes high-flow measurements of the spring all but impossible. The lowest discharge ever measured at the spring was 236 ft^3/sec on October 6, 1956.

At ***Doniphan***, near where the ***Current River*** flows into northern Arkansas, the river drains 2,038 square miles, and has an average discharge of 2,775 ft^3/sec. Based on data collected between 1918 and 1993, average runoff here is 18.50 inches. Figure 57 shows average daily discharge during 1985, the water year of highest average flow, and water year 1954, the year of lowest flow. Average discharge in water year 1985 was 5,856 ft^3/sec, and in water year 1954 it averaged 1,326 ft^3/sec. Maximum recorded flow here was 122,000 ft^3/sec, on December 3, 1982, and minimum recorded flow was 852 ft^3/sec on October 8, 1956. Figure 58 is a flow-duration curve of the Current River at *Doniphan*. Discharge here exceeds 1,170 ft^3/sec 90 percent of the time, and 1,910 ft^3/sec 50 percent of the time.

The drainage area of the ***Current River*** between *Van Buren* and *Doniphan* increases only 376 square miles. However, the average discharge and average runoff increase much more than would be expected. Average discharge increases 810 ft^3/sec, and average annual runoff increases from 16.02 inches to 18.5 inches, an increase of about 2.48 inches. Most of this increase is from springs entering the river along this reach, the largest of which is ***Big Spring***. The area recharging Big Spring lies west of the Current River. Most of the recharge comes not from within the Current River basin, but from the ***Eleven Point River*** basin. Dye tracing by Aley (1975) and other researchers show that water lost into the subsurface in part of the Eleven Point basin reappears at Big Spring. Comparing average annual runoff values for both rivers shows that runoff for the Eleven Point is less than normal for this area while that for the Current is greater than expected.

No towns in the ***Current River*** basin use surface water for municipal water supply. Groundwater in this area is easily obtained and more economical for most small towns.

Eleven Point River

The ***Eleven Point River*** rises northwest of *Willow Springs*, and drains about 1,000 square miles in Howell, Shannon, Oregon, Carter, and Ripley counties. The basin is about 60 miles long and 15 to 20 miles wide. The Eleven Point flows into the ***Black River*** in northeastern Arkansas, and like the ***Current River*** it is a popular recreational stream. Part of its reach has been designated a National Scenic River, and is under the management of the National Forest Service.

The upper part of the ***Eleven Point River***, as well as many of its tributaries, are losing streams. These drainages carry flow only briefly after heavy rainfall, or during

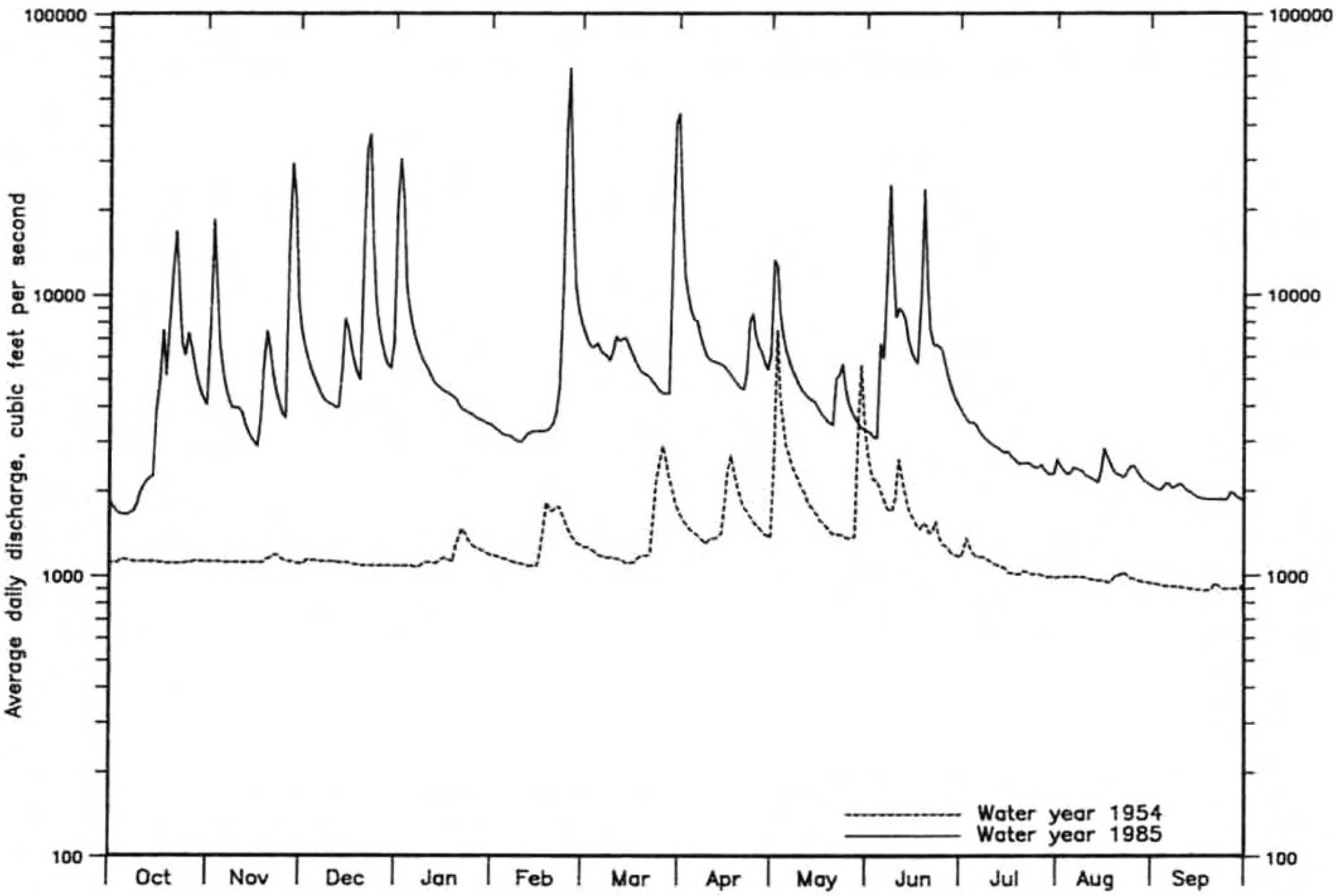

Figure 57. Average daily discharge, Current River at Doniphan, water years 1954 and 1985.

extended wet periods. From 1950 through 1975, discharge of the Eleven Point River near *Thomasville* averaged 101 ft^3/sec, and annual runoff averaged only 3.80 inches. Above Thomasville, the Eleven Point drains 361 square miles. Compare these values to those for the ***Jacks Fork*** and it can be easily seen that much of the water lost into the subsurface in the upper Eleven Point River is not returned to the stream above Thomasville. The Jacks Fork, which has a similar drainage area, 398 square miles, has much higher average discharge and runoff rates, 457 ft^3/sec and 15.60 inches, respectively.

Much of the groundwater recharge in the western and southern part of the ***Eleven Point River*** basin reappears at ***Greer Spring***, Missouri's second largest spring. Greer discharges an average of about 340 ft^3/sec from two openings developed in the Gasconade Dolomite about a mile from the Eleven Point River. Highest and lowest recorded flows for the spring are 1,770 ft^3/sec on December 3, 1982, and 104 ft^3/sec on November 19, 1956. Surface-water runoff from a 3 square mile area upstream from Greer Spring is included with the spring flow, so actual discharge of the spring during high-flow periods is slightly lower than reported values. Discharge of Greer Spring is more than 168 ft^3/sec 90 percent of the time, and exceeds 319 ft^3/sec 50 percent of the time.

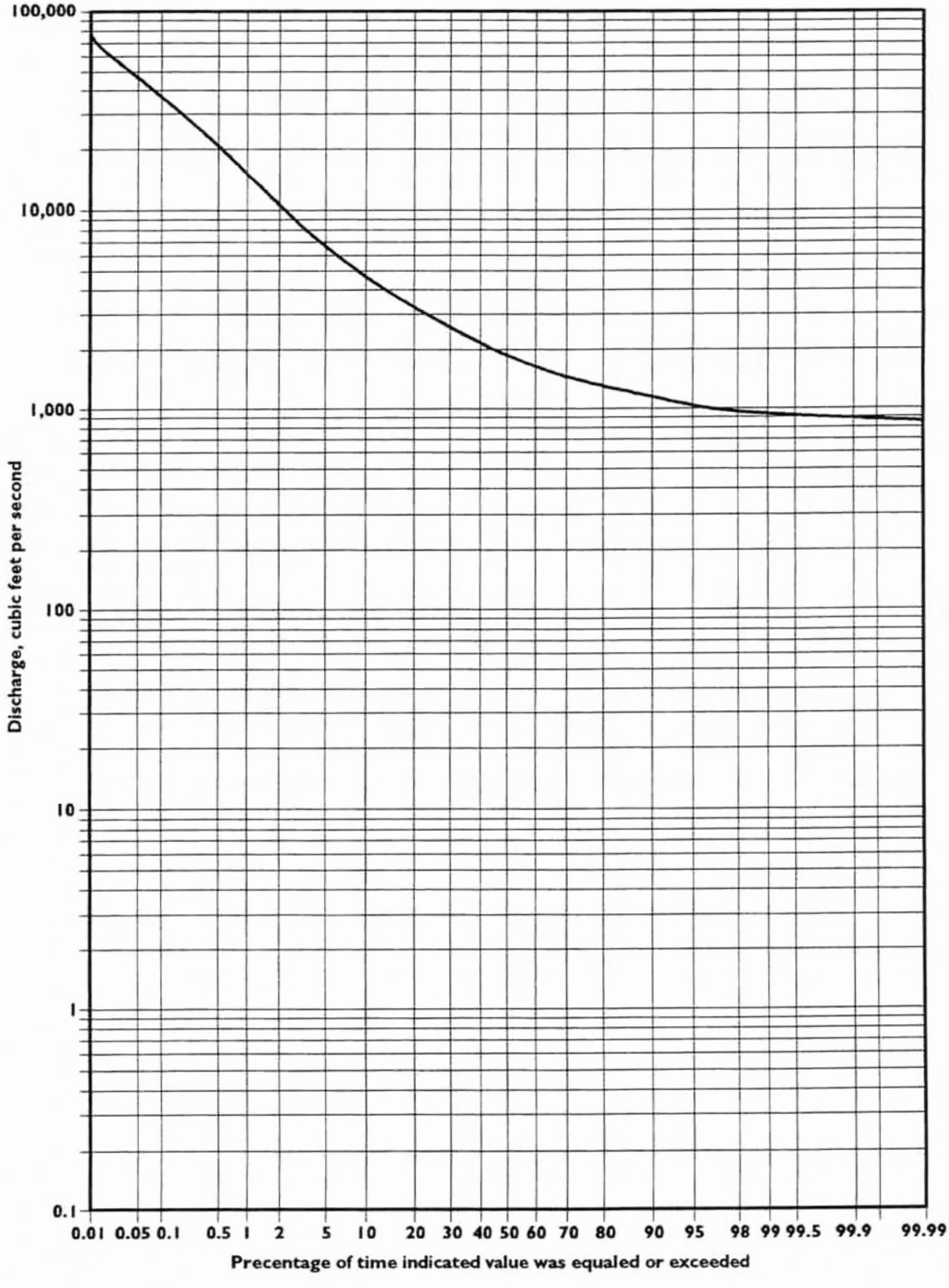

Figure 58. Flow-duration curve, Current River at Doniphan, water years 1922-1993.

Upstream from the gaging station near *Bardley* in Oregon County, the ***Eleven Point River*** drains 793 square miles. From 1921 to 1993, the river has had an average discharge of 774 ft^3/sec. Average annual runoff here is 13.26 inches, which is a considerable increase over that measured a few miles upstream at Thomasville. The increase reflects groundwater entering the river from ***Greer Spring*** and numerous other smaller groundwater outlets. Runoff, however, is still lower than it should be. This is primarily due to the subsurface movement of water from the Eleven Point basin into the ***Current River*** basin.

Dye tracing shows ***Hurricane Creek***, a major ***Eleven Point River*** tributary, and reaches of the middle Eleven Point drainage a few miles west of *Thomasville*, lose water into the subsurface that reappears at ***Big Spring*** (Aley, 1975). Based on dye tracing and flow data, it is likely that Big Spring derives as much as 80 percent of its recharge from the Eleven Point basin. Figure 59 is a flow-duration curve of the Eleven Point River near *Bardley*. Discharge here exceeds 264 ft^3/sec 90 percent of the time, and 550 ft^3/sec 50 percent of the time. Discharge in water year 1985, the highest flow year on record, averaged 1,782 ft^3/sec. In water year 1981, the lowest on record, discharge averaged 310 ft^3/sec. Maximum recorded flow for the river here was 49,800 ft^3/sec on December 3, 1982, and minimum recorded flow was 152 ft^3/sec, on January 27, 1956.

Spring River Tributaries

The ***Spring River*** is a ***Black River*** tributary that begins in southern Missouri but has most of its drainage area in northeastern Arkansas. Tributaries of the Spring River in Missouri include the ***Warm Fork Spring River, Bussell Branch-English Creek, Myatt Creek, South Fork Spring River***, and ***West Fork Spring River***. Combined, these watersheds drain only about 245 square miles in Missouri in Howell and Oregon counties.

Much of the upper watershed of the ***Warm Fork*** is characterized by losing streams and extensive sinkhole areas. ***Howell Creek***, a major tributary of the Warm Fork, is a losing stream throughout most of its reach. Dye traces by numerous researchers have shown that much of the water lost into the subsurface in this karst area provides recharge to ***Mammoth Spring***, the largest spring in Arkansas, which is on the Warm Fork Spring River a few hundred feet from the Missouri state line. Ironically, the spring outlet is within Arkansas, but essentially all of its recharge originates in Missouri.

One of the largest sinkholes in Missouri - Grand Gulf - is a few miles from Thayer in Oregon County. Grand Gulf, now a state park, is a huge sinkhole that resulted from the collapse of a cave roof. The drainage upstream of Grand Gulf, known as ***Bussell Branch***, is channelled underground through the uncollapsed cave at the low end of the sinkhole. The water reappears at ***Mammoth Spring***. ***English Creek***, which is the part of the drainage downstream of the sinkhole that was not captured by Grand Gulf, is now a wide, dry valley.

ARKANSAS RIVER TRIBUTARIES

The ***Arkansas River*** rises on the east slope of the Rocky Mountains in Colorado, and drains parts of Colorado, New Mexico, Oklahoma, Texas, Kansas, Arkansas, and Missouri. It flows into the ***Mississippi River*** in southeastern Arkansas. Tributaries of the Arkansas River in southwestern Missouri drain an area of about 2,900 square miles, or about 4.2 percent of the state. All of the tributaries flow into ***Grand Lake O' the Cherokees*** on the ***Neosho River*** in northwestern Oklahoma. The Neosho flows into the Arkansas near *Muskogee*, Oklahoma.

Nearly all of the ***Arkansas River*** basin in Missouri is within the Springfield Plateau (figure 60). The main exception to this is in northwestern Jasper and Barton counties where the basin drains part of the Osage Plains. Most of the area is underlain by Mississippian-age cherty limestones. Pennsylvanian rock forms the bedrock surface in the northwestern part of the basin, and a few windows of Ordovician rock crop out in the deeper valleys in McDonald County.

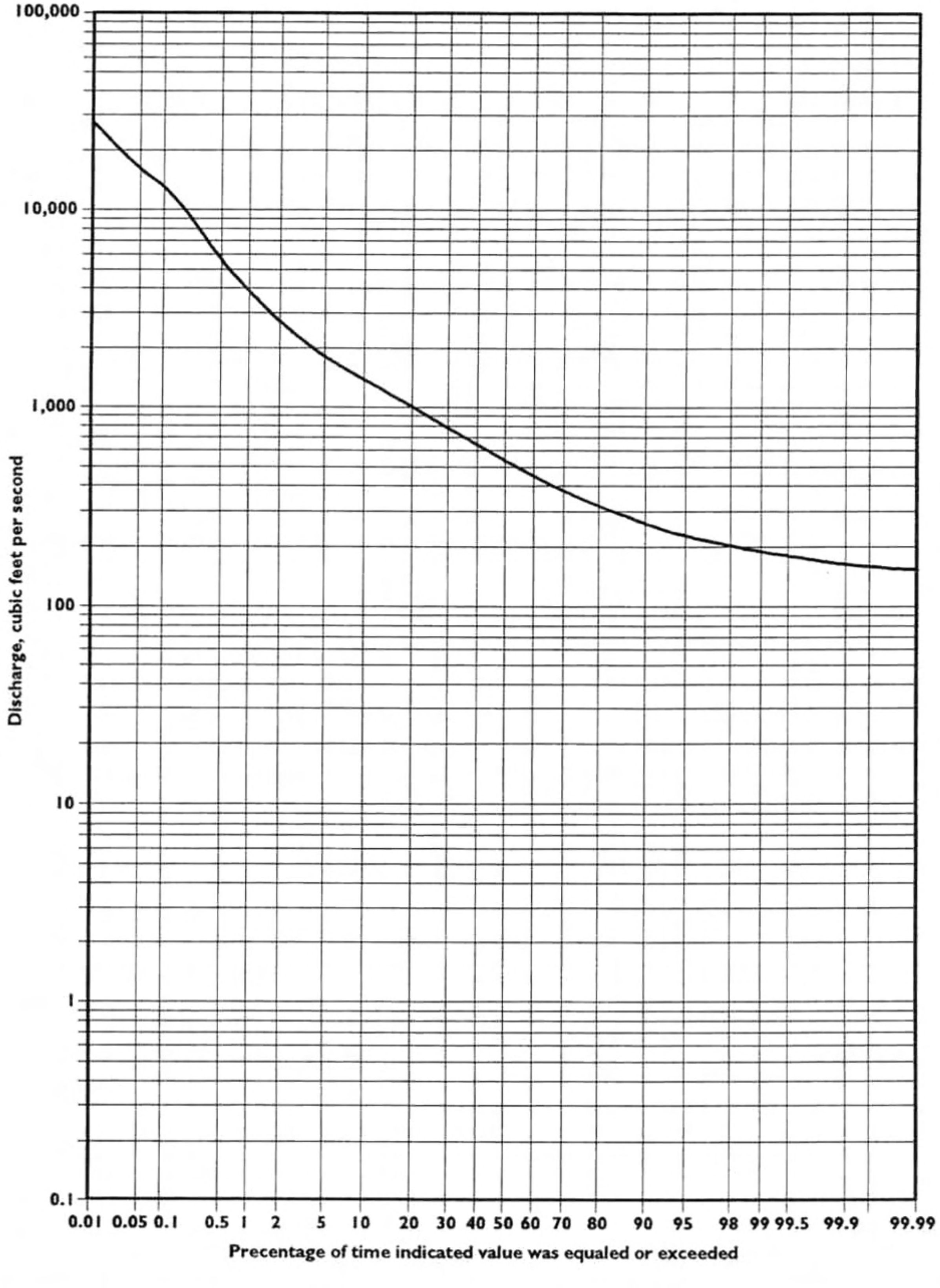

Figure 59. Flow-duration curve, Eleven Point River near Bardley, water years 1922-1993.

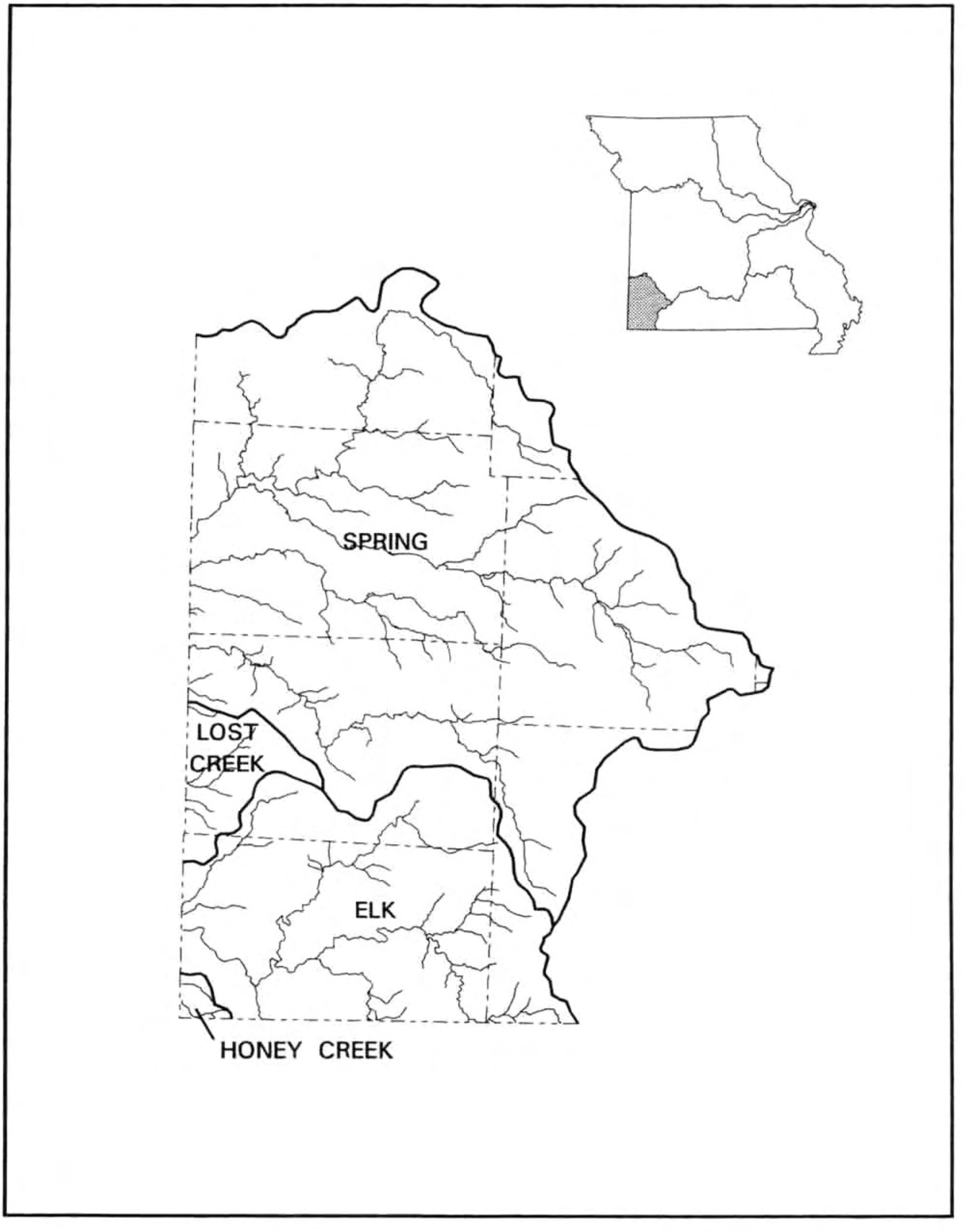

Figure 60. Arkansas River tributaries in Missouri.

Zinc and lead ores were mined in this region from the late 1800s until the 1960s, mostly in the area around *Joplin.* Mine wastes, industrial development, and municipal waste discharges adversely affect water quality in several watersheds, but water quality has shown considerable improvement during the past 20 years. Mining has ceased in the area, and there is better wastewater treatment and stricter controls on wastewater discharges. Mining in this area was underground. Surface collapses due to abandoned mine shafts, vents, and shallow mine workings allow runoff to easily enter the flooded mine workings. The water, which becomes more mineralized as it moves through the flooded mines much like water in a spring system, discharges from abandoned shafts at low elevations along some area creeks. Water from the mine workings can contain high levels of sulfate, iron, and zinc. Sulfate content of some of the mine waters exceeds 1000 mg/l, and total dissolved solids can be higher than 2,000 mg/l. Iron as high as 30 mg/l and zinc as high as 35 mg/l have been measured from mine waters. Sulfate and zinc levels in ***Center Creek*** downstream of the mining area, which receives considerable water draining from the abandoned mines, are considerably higher than those upstream from the mining area (Feder and others, 1969).

Spring River

The ***Spring River*** drains about two-thirds of the ***Arkansas River*** basin in Missouri. The River rises in southern Lawrence County, and flows north and west to the Kansas state line a few miles northwest of *Joplin.* Parts of Barton, Dade, Lawrence, Barry, and Newton counties drain into the Spring River. Its total watershed in Missouri is about 2,000 square miles. The southern and western parts of the watershed drain off the Springfield Plateau. The northwestern part of the watershed drains off of the Osage Plains. There are numerous losing streams and springs in the Springfield Plateau part of the watershed.

Upstream from *La Russell,* the ***Spring River*** drains 306 square miles. In the 24-year period between 1957 and 1981, average discharge of the river here was 243 ft^3/sec. Annual runoff averaged 10.78 inches. Springs discharging from thick Mississippian-age limestone formations provide a well-sustained base flow for the river.

Upstream from a USGS gaging station near *Waco,* near where the ***Spring River*** flows into Kansas, the river drains 1,164 square miles. Between 1924 and 1993, flow here averaged 923 ft^3/sec, and runoff averaged 10.77 in./yr. Figure 61 shows average daily flow for the Spring River near Waco in Jasper County for water years 1993 and 1954, the highest and lowest flow years. Discharge averaged 3,093 ft^3/sec in water year 1994, and 61.4 ft^3/sec in water year 1954. Maximum recorded flows here was 151,000 ft^3/sec on September 26, 1993, and minimum recorded flow was 4.2 ft^3/sec on July 28, 1954. Figure 62 shows flow-duration here. Discharge exceeds 64 ft^3/sec 90 percent of the time, and 293 ft^3/sec 50 percent of the time.

The ***Spring River*** has two major tributaries in Missouri. Both discharge into the Spring River in southeastern Kansas. ***Center Creek*** drains the central part of the Spring River basin. It rises in southern Lawrence County, and flows through northwestern Newton and southern Jasper counties. Upstream from *Carterville,* Center Creek drains about 232 square miles. Between 1962 and 1992, discharge here averaged 205 ft^3/sec, and runoff averaged 12.02 in./yr. Highest measured flow was 36,300 ft^3/sec on July 3, 1976, and the lowest measured flow was 9.4 ft^3/sec, on August 20, 1972.

Center Creek, and neighboring ***Turkey Creek***, flow through and drain water from the Duenweg-Oronogo mining area west and north of Joplin. Extensive tailings piles covered much of this area at one time. Numerous industries developed in the mining area. At one time, wastewater discharges from this area adversely affected the quality of water in ***Center Creek*** and ***Turkey Creek***. Nitrate, ammonia, phosphorous, fluoride, and zinc levels were well above acceptable limits. Mining has ceased here, but mineralized water

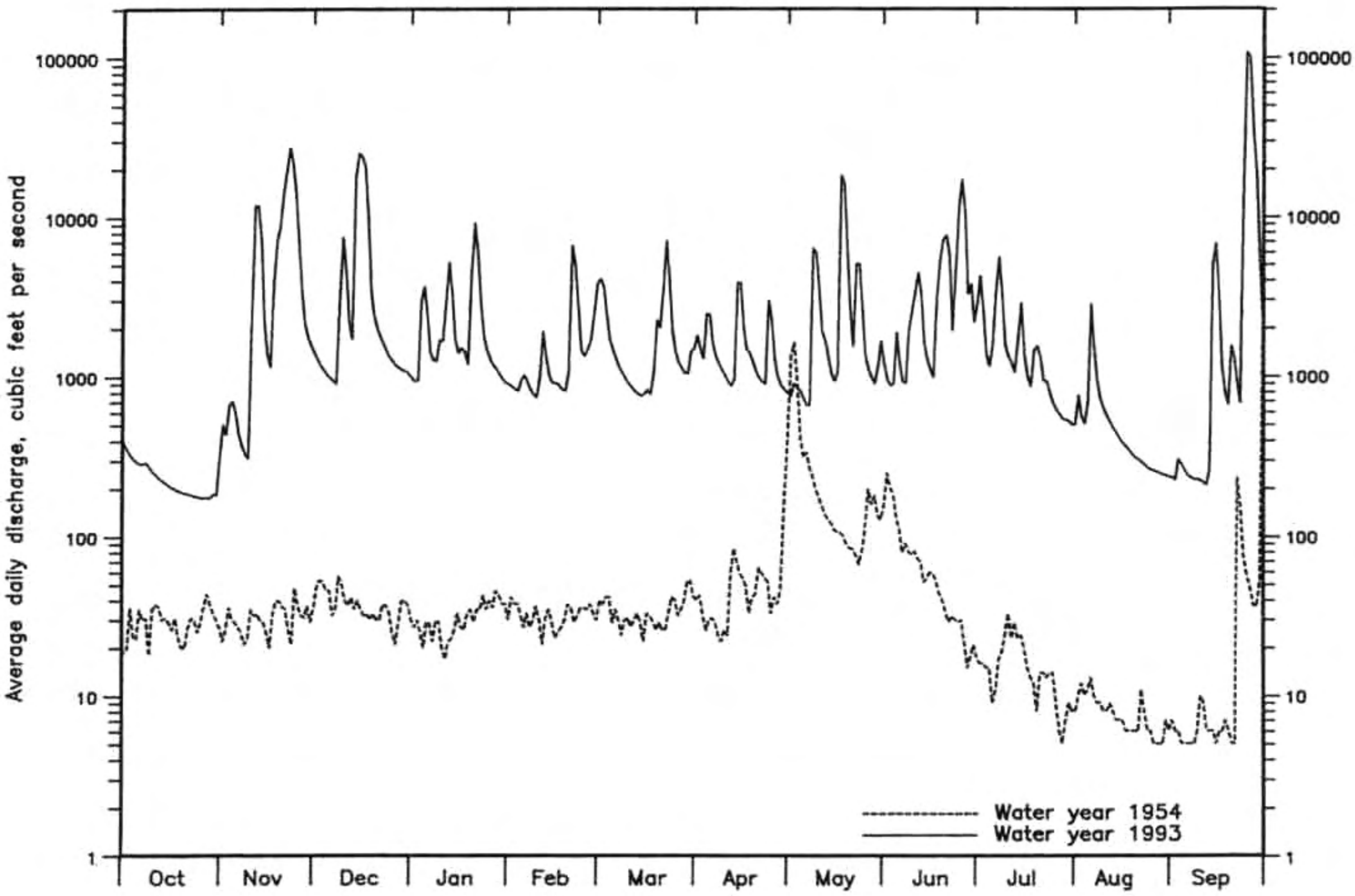

Figure 61. Average daily discharge of the Spring River near Waco, water years 1954 and 1993.

from the flooded mines discharges into Center Creek (Feder and others, 1969). Better wastewater treatment and more stringent controls on wastewater discharges have lowered contaminant levels considerably, but nutrients and zinc levels are still above normal background levels (Reed and others, 1993).

Shoal Creek drains the southern part of the ***Spring River*** basin. Its headwaters are in northwestern Barry County, and it flows through Newton and southwestern Jasper counties. Above *Joplin*, Shoal Creek drains 427 square miles, all from the Springfield Plateau. Average discharge of the creek between 1941 and 1993 was 419 ft^3/sec, and runoff averages 13.35 in./yr. Maximum flow was 62,000 ft^3/sec on May 18, 1943, and minimum flow was 12 ft^3/sec on September 7, 1954. The creek has a well-sustained, relatively high base flow provided by numerous springs in the watershed. Flow is greater than 84 ft^3/sec 90 percent of the time, and exceeds 230 ft^3/sec 50 percent of the time. The water is a calcium-bicarbonate type, reflecting the limestone bedrock of the area.

Three towns in the ***Spring River*** basin use surface water for municipal water supply needs. *Lamar*, in Barton County, uses a 180 acre lake in the upper part of the North Fork of the Spring River for municipal water supply. *Neosho* and *Joplin* in Newton and Jasper counties, respectively, use ***Shoal Creek*** for water supply.

Elk River

The ***Elk River*** drains about 850 square miles of extreme southwestern Missouri in Newton, McDonald, and Barry counties. The

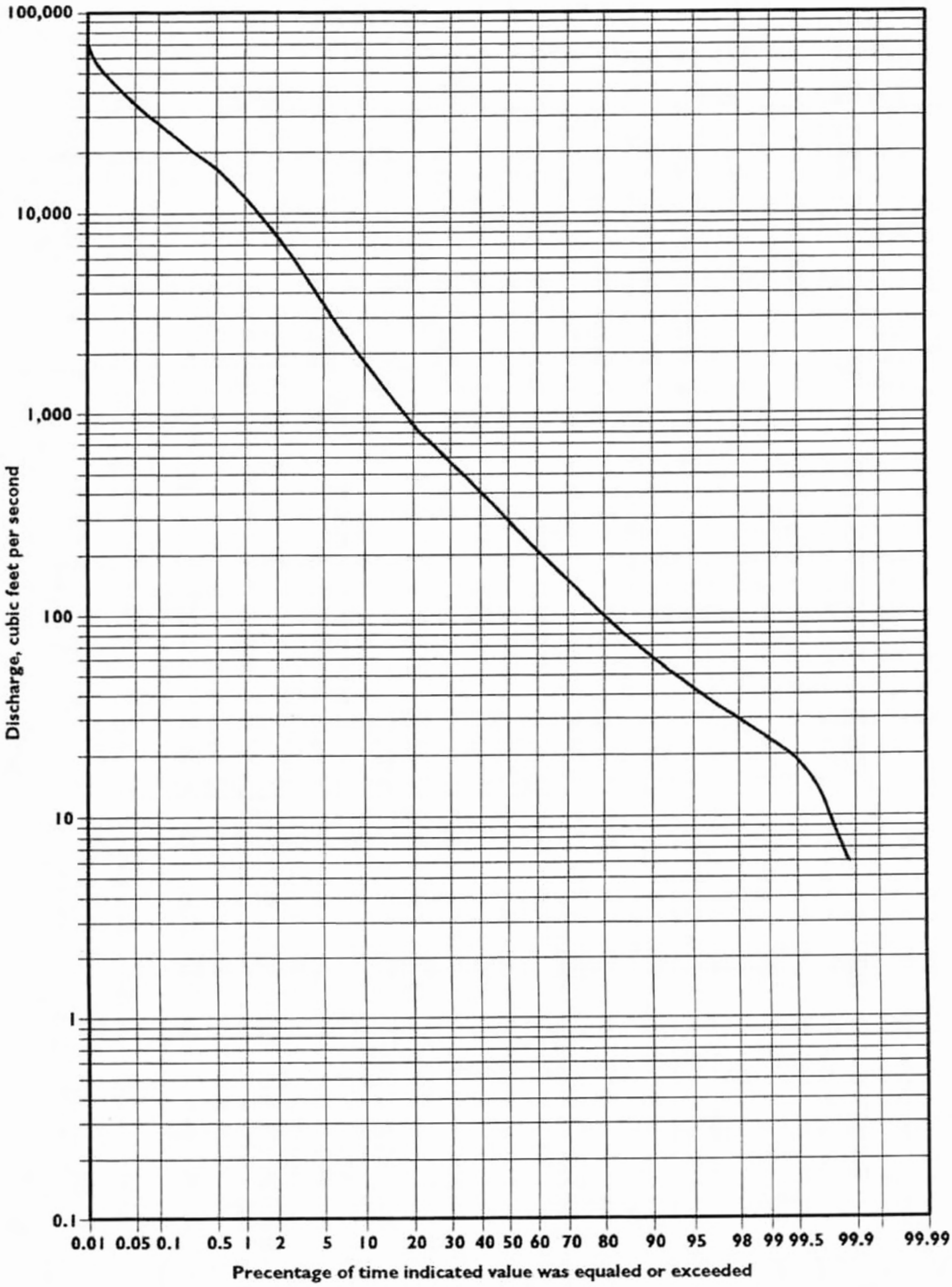

Figure 62. Flow-duration curve, Spring River near Waco, water years 1925-1993.

river begins at the confluence of ***Little Sugar*** and ***Big Sugar*** creeks near *Pineville* in McDonald County, and it flows to the west into ***Grand Lake O' the Cherokees*** in northwestern Oklahoma. Big and Little Sugar creeks drain the southern part of the watershed, including part of northwest Arkansas. The other main tributaries include ***Indian Creek***, which discharges into the ***Elk River*** 4 miles west of Pineville, and ***Buffalo Creek*** which flows into the Elk about 1 mile into Oklahoma. Indian and Buffalo creeks drain the northern part of the basin.

Most of the ***Elk River*** basin is underlain by Mississippian-age bedrock, but Devonian-age Chattanooga Shale and Ordovician-age Cotter Dolomite crop out in the lower valley walls and form the bed of the river through much of its reach. The area is within the Springfield Plateau, but the terrain is steeper and more reminiscent of Salem Plateau topography.

Upstream from near *Tiff City*, about 2 miles from the Oklahoma state line, the ***Elk River*** drains 872 square miles of southwestern Missouri and northwestern Arkansas. Drainage from ***Buffalo Creek*** enters the Elk about 3 miles downstream of the gaging station. Between 1939 and 1993, discharge of the Elk River here averaged 828 ft^3/sec, and average annual runoff is 12.9 inches. The river here has a well-sustained base flow supplied by springs in the watershed. Discharge exceeds 84 ft^3/sec 90 percent of the time, and 50 percent of the time exceeds 336 ft^3/sec (figure 63). Water years of highest and lowest average flows were 1993 and 1954, respectively. In water year 1993 discharge averaged 1,881 ft^3/sec, while in 1954 it averaged 135 ft^3/sec. Maximum recorded flow was 137,000 ft^3/sec measured on April 19, 1941, and minimum measured flow was 5.1 ft^3/sec on September 5, 1954.

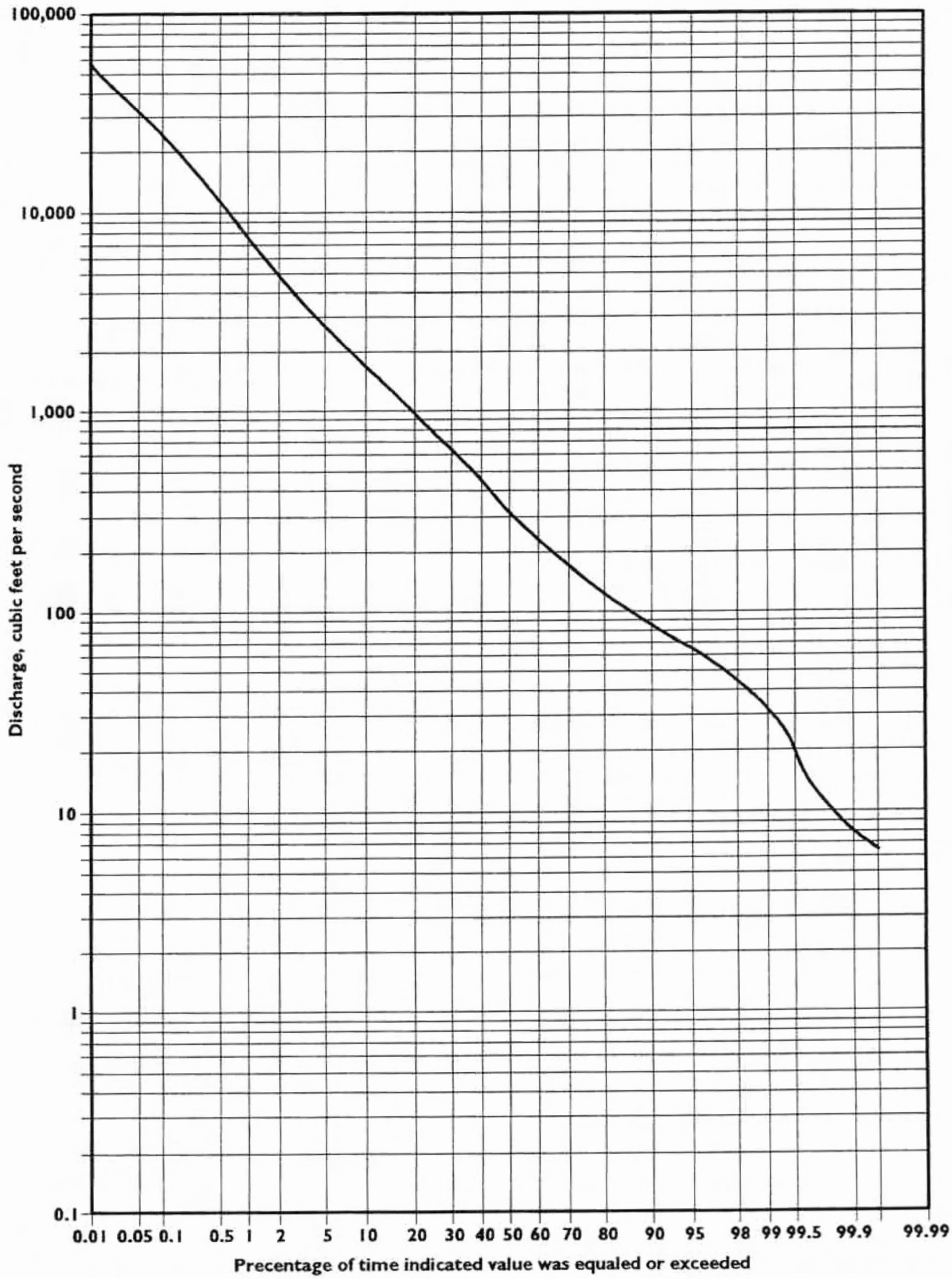

Figure 63. Flow-duration curve, Elk River near Tiff City, water years 1940-1993.

CONCLUSIONS

Missouri depends greatly on its surface-water resources for drinking water, agricultural needs, commercial and industrial water supply, river transportation, fish and wildlife habitat, recreation, electrical production, and a myriad of other uses.

More than 120 water-supply reservoirs are currently in use by Missouri communities, and all but a few are located in northern and western parts of the state. This is due, in large part, to the lack of adequate groundwater resources in northern and west-central Missouri.

Water-supply intakes on rivers and streams are used by more than 50 cities in areas where streams have adequate flows during dry weather. Reservoirs are more typically used where streams have poorly-sustained base flows, or where towns are too far from a river to economically construct an intake and pipeline. About 20 towns, however, use both a reservoir for impounding runoff and a river intake to supplement their inflow from runoff.

From the earliest days of settlement, the rivers of Missouri have been the lifeblood of the communities along them. They have supplied water, carried away wastes, and served as highways. In fact, many of the cities and towns along the rivers use them in much the same ways today as they did more than a century ago. But, because of larger populations in these cities today, the flows of the rivers have become even more essential. Nearly 60 percent of the population of Missouri lives in the 25 counties bordering the Missouri River. Currently, the Missouri and Mississippi rivers together supply municipal water to more than one-third of the state's population.

Surface water is viewed somewhat differently in the southern half of the state. Here, groundwater is readily available and of excellent quality, so surface water is used much less for municipal water supply. However, tourism and recreation, which are extremely important industries for the state, depend heavily on surface water. Major lakes in the Osage, St. Francis, and White River basins provide excellent water-based recreation as well as hydroelectric power. The spring-fed rivers and streams in the Ozarks are some of the most scenic waters in the nation. Their protection is paramount to the economic well being of the people in southern Missouri.

The basin-by-basin assessment of Missouri surface-water resources in this report shows that the surface-water resources of Missouri are generally adequate to meet current water needs. This does not mean that the availability of water is not a problem. On the contrary, some northern and western Missouri towns face water shortages during extended droughts. Often, this is because the aging reservoirs serving many of the towns are becoming inadequate. Per capita water use and population have increased for many of these towns, but reservoir sedimentation has diminished the amount of reservoir storage space available. New reservoirs are expensive, and many towns have found it difficult to keep pace with their growing water-supply needs. In the past, water shortages triggered by drought convinced some towns of the need for a new reservoir. Unfortunately, a new reservoir is of little use until runoff from rainfall can fill it.

In this report, the description of nearly every stream and river includes its average flow. If every year were an "average" year, water-supply problems would probably be negligible. In reality, though, the average flow of a stream includes only a few years that are about average. There are many more years when flows are above or below normal. Occasionally, flows are very low or extremely high.

Most water-related problems do not arise during average conditions, they arise during climatic extremes. Flooding and drought are the seeds of many natural disasters. Neither event can be predicted nor eliminated, but adequate planning on a local as well as a regional scale can lessen their severity. Each climatic extreme requires a different approach. For water supply, droughts must be carefully considered to minimize the chances of a supply becoming inadequate during extended dry weather. Obviously, dams and intake structures also have to be designed to withstand flooding. Droughts generally do not damage bridges, homes, levees, and roads, but floods almost always do. Any project dealing with development along or near a stream requires a thorough understanding of the high-flow characteristics of the stream.

It must be remembered that the rivers and streams in Missouri provide much more than just raw water. For aquatic species, as well as waterfowl and other wildlife, rivers and streams mean survival. The quantity of water, and the quality of that water, directly affects the quantity and quality of the fauna it supports. To protect these species, as well as the social and economic well-being of the people of Missouri, the quantity and quality of the state's water resources must be protected.

REFERENCES CITED

Alexander, Jim, 1995, Chief Engineer and Program Director, Dam and Reservoir Safety Program, Missouri Department of Natural Resources, Division of Geology and Land Survey, personal communication, January, 1995.

Aley, Thomas, 1975, *A predictive hydrologic model for evaluating the effects of land use and management on the quantity and quality of water from Ozark springs:* Prepared for the National Forests in Missouri under contract 05-1277 by Ozark Underground Laboratory, Protem, Missouri, 259 p.

___, 1978, *Hydrologic studies of springs, Ozark National Scenic Riverways, Missouri,* Ozark Underground Laboratory, Protem, Missouri, 107 p.

Beveridge, Thomas R., 1992, *Geologic wonders and curiosities of Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, Educational Series No. 4, 392 p.

Bolon, Harry C., 1960, *Subterranean drainage of the Gasconade River between Hazelgreen and Waynesville,* Missouri in *Guidebook to the geology of the Rolla area, emphasizing solution phenomena:* Prepared for the fifth annual Midwest Groundwater Conference, Missouri Geological Survey and Water Resources, pp. 23-25.

Brown, James, 1988, *Summary of dye trace from Summer's Spring to Double, North Fork and Hodgson Mill springs* in *Dye Trace Data Base:* Missouri Department of Natural Resources, Division of Geology and Land Survey, computer data base.

Division of Environmental Quality (DEQ), 1991, *Census of Missouri public water systems:* Missouri Department of Natural Resources, Division of Environmental Quality, 182 p.

Feder, G.L., John Skelton, H.G. Jeffery, and E.J. Harvey, 1969, *Water resources of the Joplin area, Missouri:* Missouri Geological Survey and Water Resources, Water Resources Report No. 24, 97 p.

Gann, E.E., E.J. Harvey, H.G. Jeffery, and D.L. Fuller, 1971, *Water resources of northeastern Missouri:* U.S. Geological Survey, Hydrologic Investigations Atlas HA-372, 4 sheets.

Gann, E.E., E.J. Harvey, J.H. Barks, and D.L. Fuller, 1973, *Water resources of northwestern Missouri:* U.S. Geological Survey, Hydrologic Investigations Atlas HA-444, 4 sheets.

Gann, E.E., E.J. Harvey, J.H. Barks, D.L. Fuller, and D.E. Miller, 1974, *Water resources of west-central Missouri:* U.S. Geological Survey, Hydrologic Investigations Atlas HA-491, 4 sheets.

Gann, E.E., E.J. Harvey, and D.E. Miller, 1976, *Water resources of south-central Missouri:* U.S. Geological Survey, Hydrologic Investigations Atlas HA-550, 4 sheets.

Hoffman, David, 1980, *Inventory of non-federal dams in Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, prepared for the U.S. Army Corps of Engineers, St. Louis District, 300 p. (approx.)

______, Palmer, J.R., Harrison, R.W., Odum, J.K., Stephenson, W.J., and Williams, R.A., 1994, *Faulting associated with the southeastern escarpment of the Benton Hills, Scott County, Missouri (abs.)*: South-Central Section, Geol. Soc. of Amer., Abstracts with Program, v. 26, no. 1, p. 8.

Miller, Don E., and Vandike, James E.,1996, *State water plan series-volume 2, groundwater resources of Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 45, (in preparation).

Miller, John C., 1971, *Groundwater resources of Saline County, Missouri:* Missouri Geological Survey and Water Resources, Water Resources Report No. 26, 75 p.

Missouri Geological Survey (MGS), 1967, *Mineral and water resources of Missouri:* Missouri Geological Survey and Water Resources, Vol. 43, Second Series, 399 p.

Missouri Water Atlas, 1986, Missouri Department of Natural Resources, Division of Geology and Land Survey, 100 p.

Reed, H.L., T.J. Perkins, and G.L. Gray, Jr., 1993, *Water resources data for Missouri, water year 1993:* U.S. Geological Survey, Water-Data Report MO-93-1, 275 p.

Skelton, John, 1966, *Low-flow characteristics of Missouri streams:* Missouri Geological Survey and Water Resources, Water Resources Report No. 20, 95 p.

______, 1971, *Carryover storage requirements for reservoir design in Missouri:* Missouri Geological Survey and Water Resources, Water Resources Report No. 27, 60 p.

South Dakota (SD), 1975, *Mineral and water resources of South Dakota:* U.S. Geological Survey, printed for the use of the Committee on Interior and Insular Affairs, 94th Congress, 1st session, 313 p.

U.S. Army Corps of Engineers, 1994, *Master water control manual, Missouri River, Volume 6D:* U.S. Army Corps of Engineers, Missouri River Division, Vol. 6D.

U.S. Department of Commerce, 1956, *Climatological data, Missouri, annual summary:* U.S. Department of Commerce, Weather Bureau, Vol. 60, No. 13, 13 p.

______, 1957, *Climatological data, Missouri, annual summary:* U.S. Department of Commerce, Weather Bureau, Vol. 61, No. 13, 13 p.

______, 1980, *Climatological data, Missouri, annual summary:* National Oceanic and Atmospheric Administration, National Climatic Center, Vol. 84, No. 13, 18 p.

______, 1988, *Climatological data, Missouri, annual summary:* National Oceanic and Atmospheric Administration, National Climatic Center, Vol. 92, No. 13, 36 p.

______, 1990, *Climatological data, Missouri, annual summary:* National Oceanic and Atmospheric Administration, National Climatic Center, Vol. 94, No. 13, 36 p.

______, 1993, *Climatological data, Missouri, annual summary:* National Oceanic and Atmospheric Administration, National Climatic Center, Vol. 97, No. 13, 38 p.

Vandike, James E., 1992a, *Results of dye tracing along the Interstate-44 corridor, western Pulaski County, Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, unpublished open-file report, 5 p.

____, 1992b, *The hydrogeology of the Bennett Spring area, Laclede, Dallas, Webster, and Wright counties, Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 38, 112 p.

________, 1993, *Groundwater level data for Missouri: Water year 1991-1992:* Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 42, 96 p.

____, 1996, *The hydrogeology of the Maramec Spring area:* Missouri Department of Natural Resources, Division of Geology and Land Survey (in preparation).

Vineyard, Jerry D., and Gerald L. Feder, 1974, *Springs of Missouri:* Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 29, 267 p.

Williams, C.E., 1986, *Summary of dye trace from Wolf Creek to Double, North Fork, and Hodgson Mill Springs* in *Dye Trace Database:* Missouri Department of Natural Resources, Division of Geology and Land Survey, computer data base.

Williams, C.E., 1987, *Summary of dye trace from Fry Creek to Double, North Fork and Hodgson Mill Springs* in *Dye Trace Database:* Missouri Department of Natural Resources, Division of Geology and Land Survey, computer data base.